# Microwave Sounding in All-Weather Conditions and Plans for NPP/ATMS

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# Agenda

- Context
- Description of MiRS
- Results of MiRS for NOAA and Metop
- Plans for NPP ATMS

# Context

- NOAA/NESDIS/STAR is developing a consistent, unique physical algorithm for all microwave sensors (called MiRS: Microwave Integrated Retrieval System)
- MiRS applies to imagers, sounders, combination
- MiRS uses the Community Radiative Transfer Model (CRTM) as the forward operator
- MiRS is applicable on all surfaces and in all-weather conditions (including in presence of cloud, rain, ice)
- MiRS is running operationally for NOAA-18, Metop-A and DMSP SSMI/S
- **Purpose:** Get ready for the NPP and NPOESS era. To use MiRS for ATMS and potentially for MIS.

# Description of MiRS

# MiRS Overall Concept

**Variational Assimilation Retrieval (1DVAR) Algorithm**

CRTM as forward operator, validity-> clear, cloudy and precip conditions

Emissivity spectrum is part of the retrieved state vector

**Algorithm valid in all-weather conditions, over all-surface types**

**Cloud & Precip profiles retrieval (no single cloud top, thickness paramaters)**

EOF decomposition

**Sensor-independent (all sensor-dependent info is passed in through external files)**

Highly Modular Design

**Flexibility and Robustness**

Selection of Channels to use, parameters to retrieve

Modeling & Instrumental Errors are input to algorithm

# Mathematical Basis

- Cost Function to minimize:

$$J(X) = \left[\frac{1}{2}(X - X_0)^T \times B^{-1} \times (X - X_0)\right] + \left[\frac{1}{2}\left(Y^m - Y(X)\right)^T \times E^{-1} \times \left(Y^m - Y(X)\right)\right]$$

- To find the optimal solution, solve for:

$$\frac{\partial J(X)}{\partial X} = J'(X) = 0$$

- Assuming local Linearity

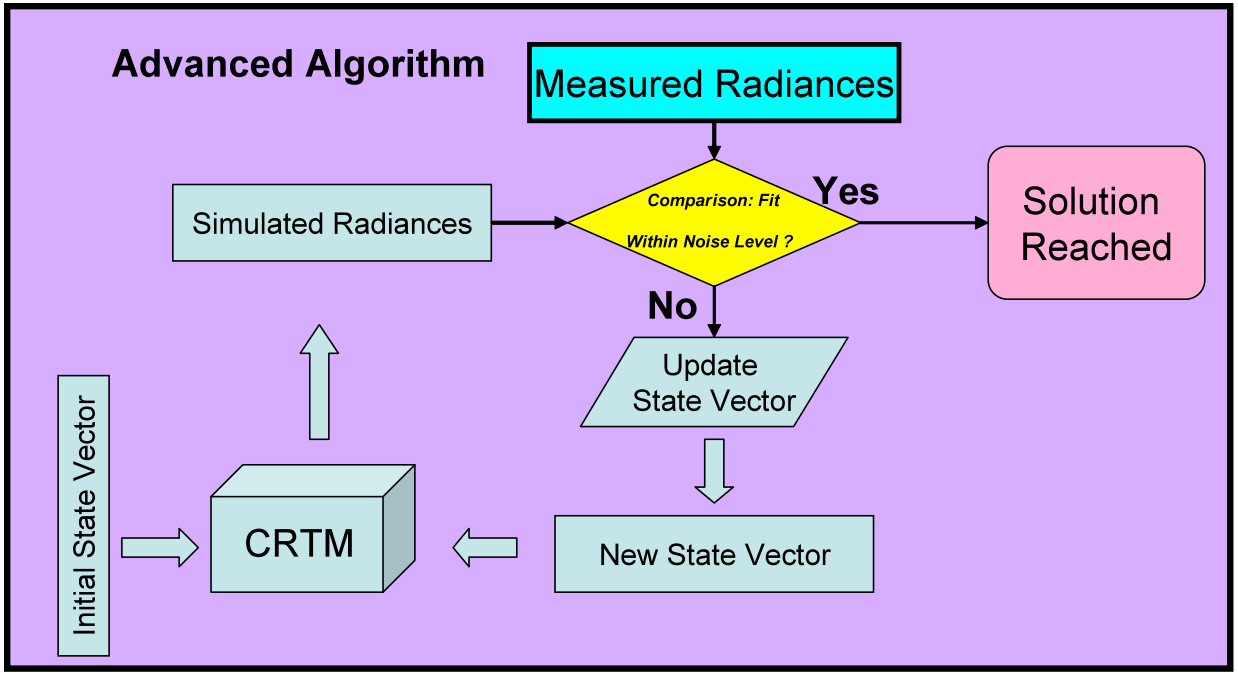
$$y(x) = y(x_0) + K\left[x - x_0\right]$$

- This leads to iterative solution:

$$\Delta X_{n+1} = \left\{BK_n^T\left(K_n B K_n^T + E\right)^{-1}\right\}\left[\left(Y^m - Y(X_n)\right) + K_n \Delta X_n\right]$$

More efficient
(1 inversion)

# MiRS Algorithm (1DVAR)




The first retrieval attempt includes only clear and cloudy (non-precipitating) parameters

Convergence

Final solution (no precip)

Non-Convergence

2nd Attempt (liquid and ice rain turned ON along with all sounding/surface parameters)

# MIRS State Vector

- Temperature & Water vapor profiles @ 100 layers
- Skin Temperature
- Surface Emissivity Spectrum
- Non-precipitating cloud amount vertical profile
- Liquid and frozen rain vertical profiles

# Assumptions Made in Solution Derivation

- The PDF of X is assumed Gaussian
- Operator Y able to simulate measurements-like radiances
- Errors of the model and the instrumental noise combined are assumed (1) non-biased and (2) Normally distributed.
- Forward model assumed locally linear at each iteration.
- Independence of errors (instrumental and background)

# Retrieval in Reduced Space (EOF Decomposition)

- All retrieval is done in EOF space, which allows:
  - Retrieval of profiles (T,Q, RR, etc): using a limited number of EOFs
  - More stable inversion: smaller matrix but also quasi-diagonal
  - Time saving: smaller matrix to invert

- Mathematical Basis:
  - EOF decomposition *(or Eigenvalue Decomposition)*
    - By projecting back and forth Cov Matrx, Jacobians and X

$$\boxed{\Theta = L^T \times B \times L}$$

**Diagonal Matrix**
*(used in reduced space retrieval)*

**Transf. Matrx**
*(computed offline)*

**Covariance matrix**
*(geophysical space)*

# Purpose(s) of Retrieving Precipitation Parameters

- #1: Be able to retrieve Temperature mainly (possibly water vapor as well) under precipitating conditions
- #2: Retrieve precipitation parameters themselves ONLY if enough information content present (not the case currently)

- Think of it as a 'PRECIP- CLEARING' but highly non-linear : Account for precip only to absorb extinction effects on radiances and allow retrieval of T/Q.

# MIRS Convergence Criteria

- Convergence should check for minimal cost function J

$$J(X) = \underbrace{\left[\frac{1}{2}(X - X_0)^T \times B^{-1} \times (X - X_0)\right]}_{\text{Bkg-departure normalized by Bkg Error}} + \underbrace{\left[\frac{1}{2}(Y^m - Y(X))^T \times E^{-1} \times (Y^m - Y(X))\right]}_{\text{Measurements-departure normalized by Measurements+Modeling Errors}}$$

- In practice, we use non-constrained cost Function:

$$\varphi^2 = (Y^m - Y(X))^T \times E^{-1} \times (Y^m - Y(X))$$

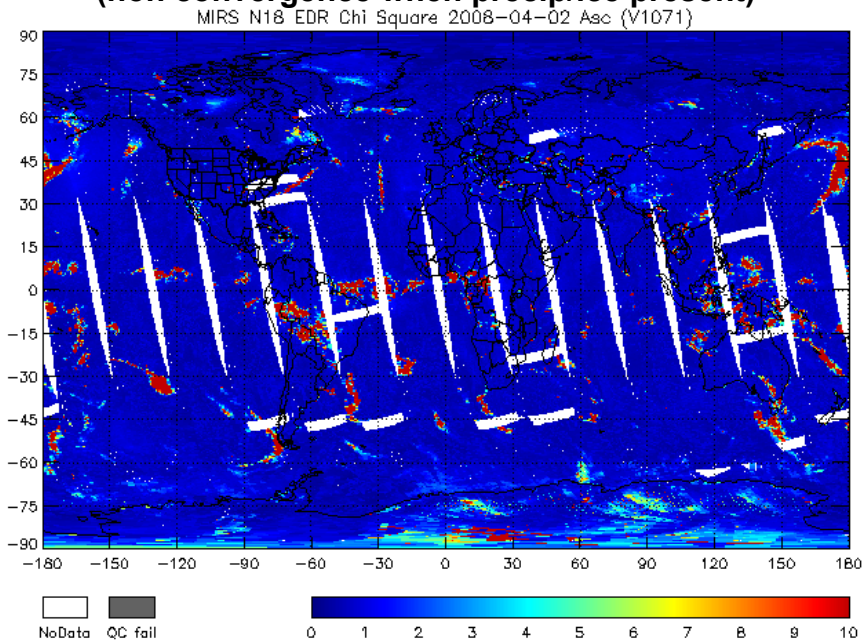
- Convergence threshold $\varphi^2 <= 1$

# Convergence Example

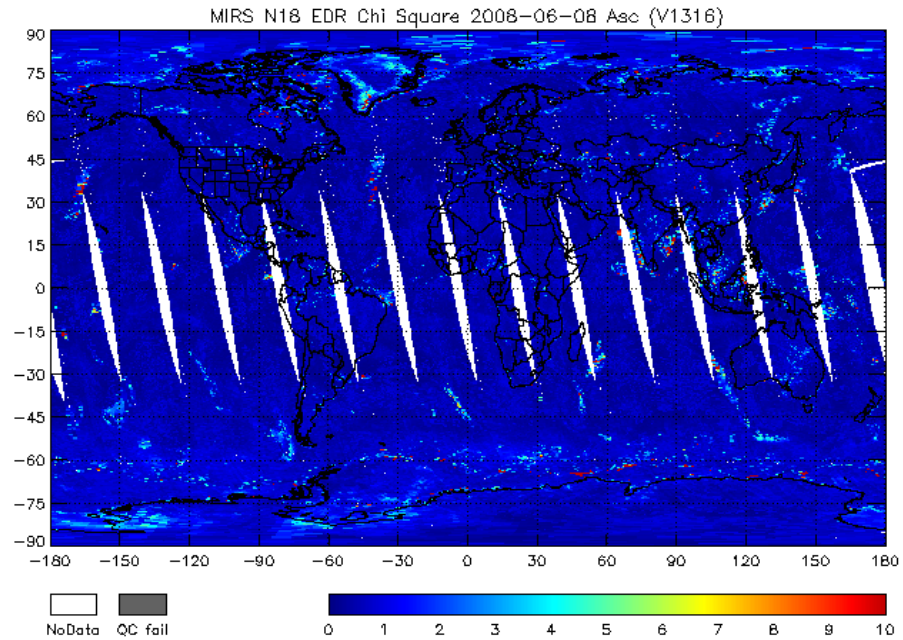
- Convergence is reached everywhere: all surfaces, all weather conditions including precipitating, icy conditions
- This is a major achievement: a radiometric solution is found even when precip/ice present. With CRTM physical constraints and covariance-based correlations.

**Previous version**

**(non convergence when precip/ice present)**




**Current version**



# List of products (Official)

- **Metop-A and NOAA-18**
  1. Temperature profile (ocean)
  2. Moisture (ocean and non-costal land)
  3. Total Precipitable Water (TPW) (ocean and non-costal land)
  4. Land Surface Temperature (LST)
  5. Emissivity Spectrum (All surfaces)
  6. Surface Type (sea, land, snow, sea-ice)
  7. Emissivity-based Snow Water Equivalent (SWE)
  8. Emissivity-based Snow Cover Extent (SCE)
  9. Emissivity-based Sea Ice Concentration (SIC)
  10. Vertically Integrated Non-precipitating Cloud Liquid Water (CLW)
  11. Vertically Integrated Ice Water Path (IWP)
  12. Vertically Integrated Rain Water Path (RWP)

**Note: The hydrometeor profiles dropped from official list (lack of information content in radiances, see next slide)**

- **DMSP F16 SSMIS**
  1. Temperature profile (ocean)
  2. Moisture (ocean and non-costal land)
  3. Total Precipitable Water (TPW) (ocean and non-costal land)
  4. Land Surface Temperature (LST)
  5. Emissivity Spectrum (All surfaces)
  6. Surface Type (sea, land, snow, sea-ice)

**Total: 30 products**

# List of unofficial products

**(Delivered For Testing purposes)**

**Note: Cl made availa sting purposes (sc de)**

- **Metop-A and NOAA-18**
  1. Cloud Liquid Water Profile (CLWP) over ocean
  2. Surface Temperature (skin) of snow-covered lan
  3. Sea Surface Temperature (SST)
  4. Effective grain size of snow (over snow-co d surface)
  5. Multi-Year (MY) Type Sea Ice concentra
  6. First-Year (FY) Type Sea Ice Concer

- **DMSP F16 SSMIS**
  1. Extended Total Precipitabl over non-coastal Land
  2. Emissivity-based Snow quivalent (SWE)
  3. Emissivity-based Sn r Extent (SCE)
  4. Emissivity-based Concentration (SIC)
  5. Surface Temp (skin) of snow-covered land
  6. Sea Surfac erature (SST)
  7. Effectiv ze of snow (over snow-covered land surface)
  8. Multi Y) Type Sea Ice concentration
  9. Fi (FY) Type Sea Ice Concentration

We will concentrate on the sounding aspect only.

**Total: 21 test products**

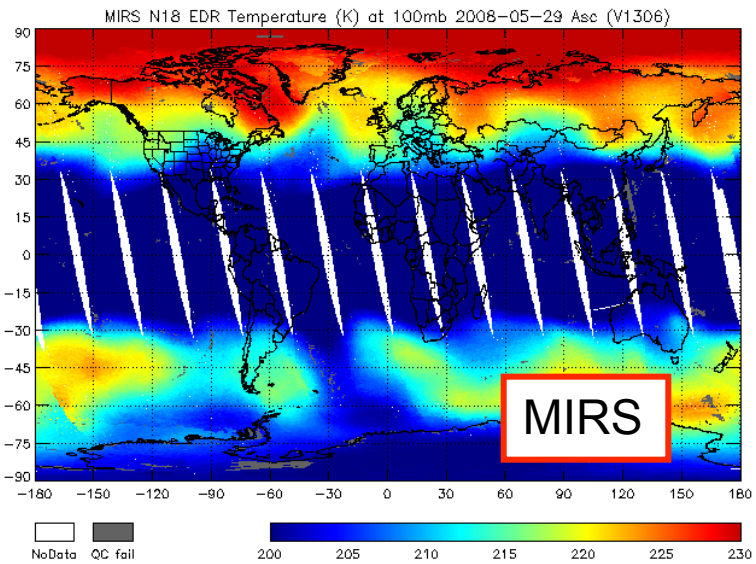
# Results of MiRS for NOAA-18 and Metop-A

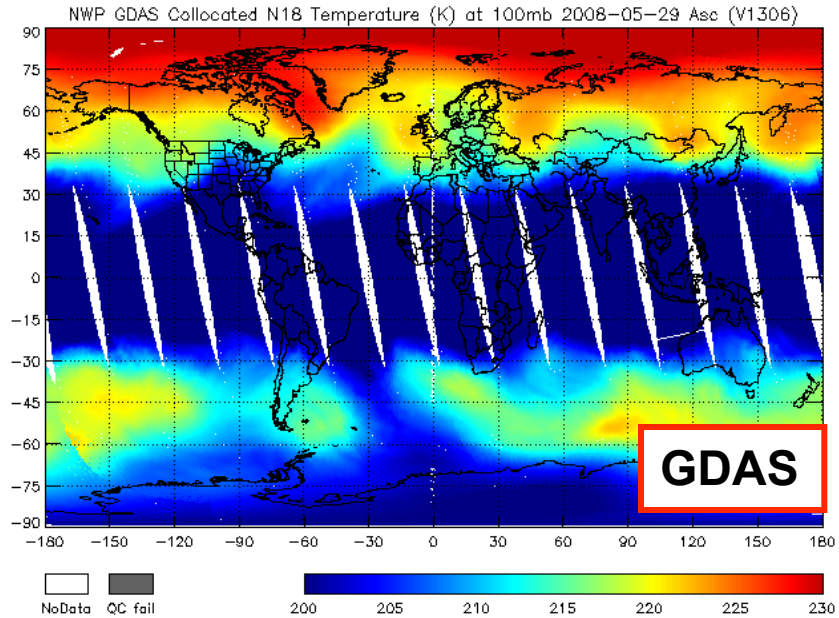
# Assessment of Sounding Performances in Clear/Cloudy

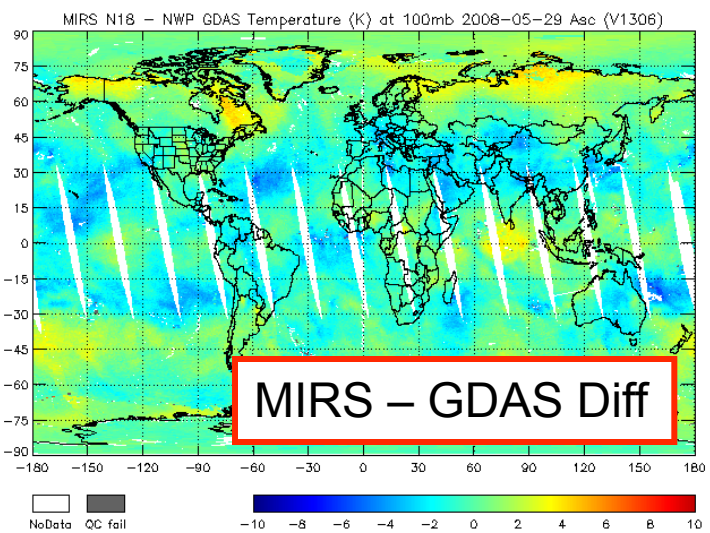
*Comparisons made daily wrt:*
*- GDAS fields*
*- ECMWF fields*
*- COSMIC profiles*
*- Radiosondes profiles*
*- Heritage sounding algorithms (ATOVS)*

# Temperature Profile (1/4)

## (over open water ocean, against GDAS)

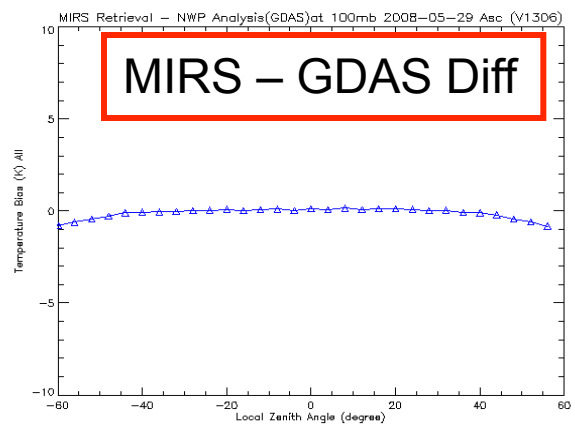



**The temperature is officially delivered over ocean only. But over non-ocean (land, snow, sea ice), temperature is still valid.**

**Validation is performed by comparing to:**
**-GDAS**
**-ECMWF**
**-RAOB**

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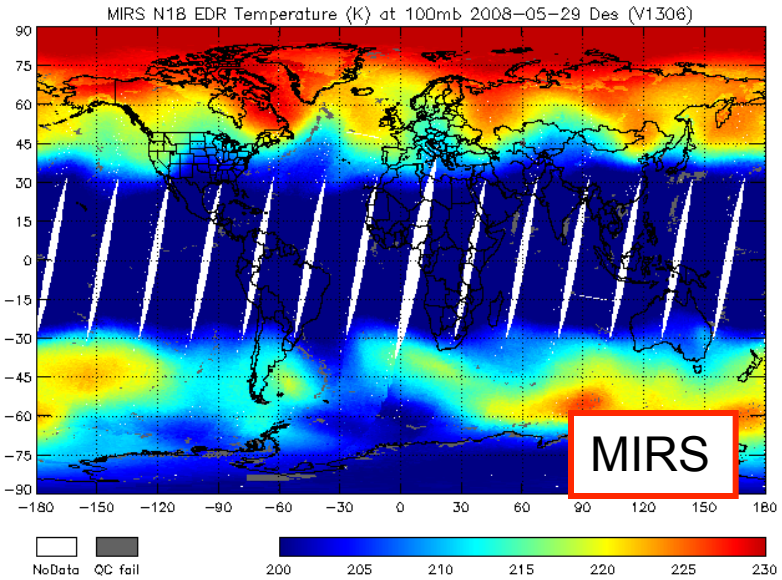
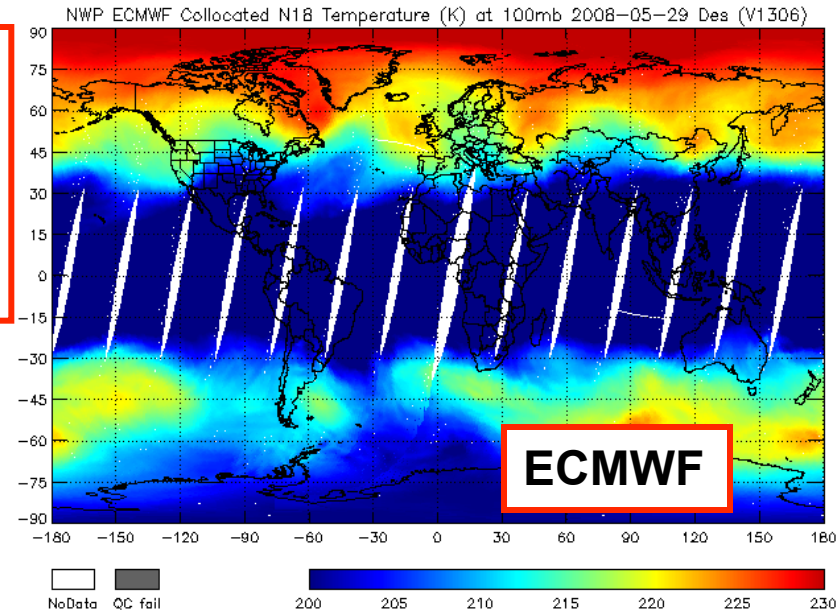
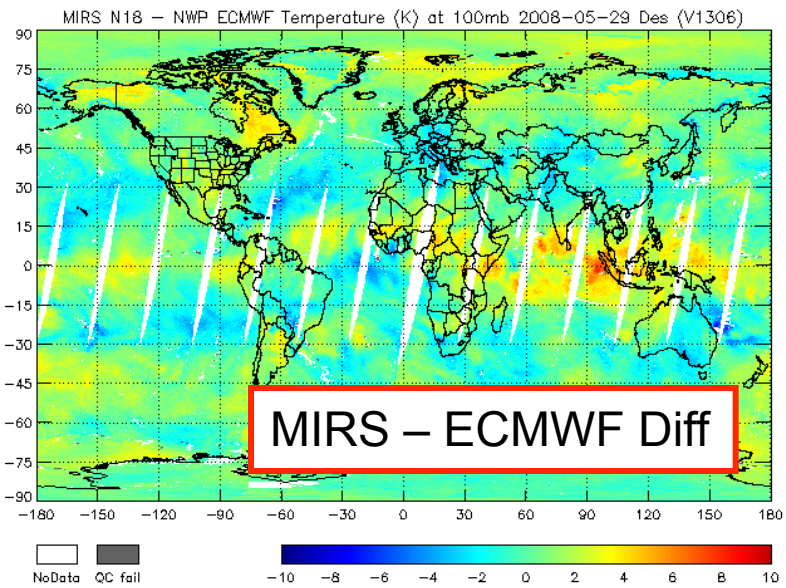
# Temperature Profile (2/4)

## (over open water ocean, against ECMWF)

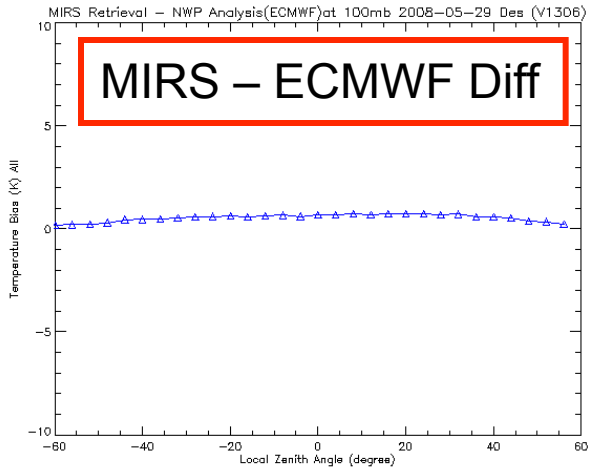



**Angle dependence taken care of very well, without any limb correction**



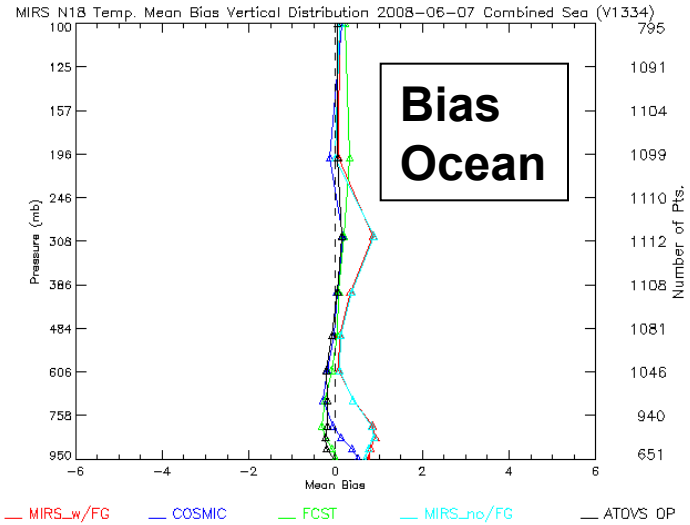



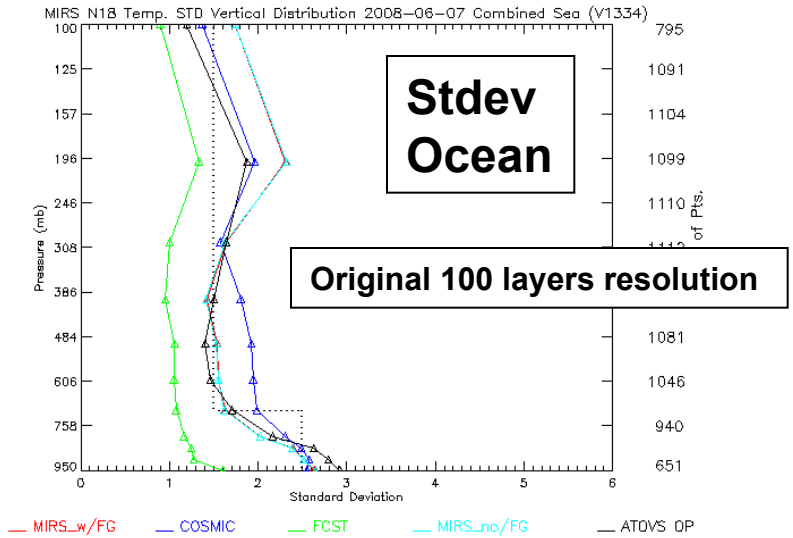

**Note: Retrieval is done over all surface backgrounds but also in all weather conditions (clear, cloudy, rainy, ice)**



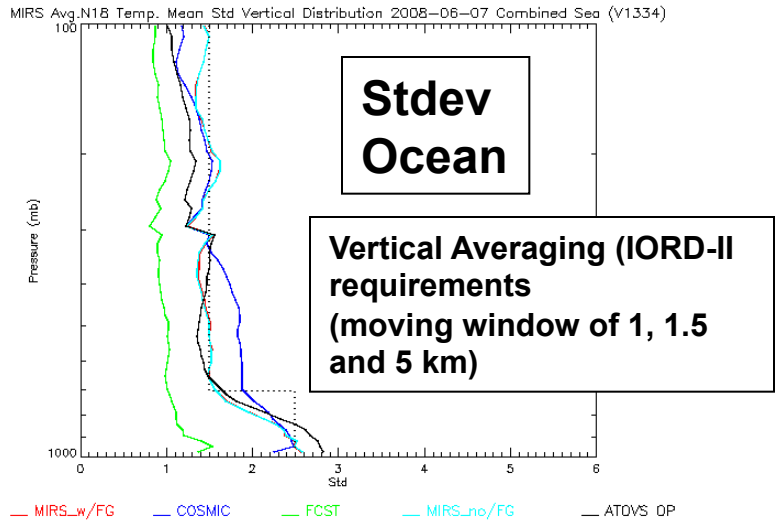
# Temperature Profile (3/4)

## (over open water ocean, against RAOBs, COSMIC, ATOVS, Forecast)




Bias of roughly 1 K noticed at the surface




Collocation criteria (COSMIC, ATOVS, SSMIS, RAOB):
+/- 5 hours, +/- 100 Kms
Data spanning 42 days

N18

# Temperature Profile (4/4)

(Performances)

| | Layer | Ocean Bias (K) | Ocean Std (K) | Land Bias (K) | Land Std (K) |
|---|---|---|---|---|---|
| *MIRS vs ECMWF* | 100 mb | 0.281 | 1.883 | 1.019 | 1.787 |
| | 300 mb | 0.273 | 1.504 | 0.548 | 1.701 |
| | 500 mb | 0.059 | 1.311 | 0.241 | 1.806 |
| | 800 mb | 1.169 | 1.823 | 1.157 | 3.410 |
| | 950 mb | 1.727 | 2.736 | 0.860 | 4.480 |
| *MIRS vs GDAS* | 100 mb | -0.0485 | 1.541 | 0.017 | 1.708 |
| | 300 mb | 0.183 | 1.589 | 0.151 | 1.801 |
| | 500 mb | -0.197 | 1.401 | 0.245 | 1.847 |
| | 800 mb | 1.152 | 1.711 | 1.277 | 3.826 |
| | 950 mb | 1.107 | 2.808 | 0.881 | 4.826 |
| *MIRS vs RAOB* | 100 mb | 0.080 | 1.739 | 0.259 | 2.085 |
| | 300 mb | 0.851 | 1.858 | 0.489 | 1.774 |
| | 500 mb | 0.123 | 1.578 | -0.062 | 1.811 |
| | 800 mb | 0.681 | 2.082 | 1.501 | 2.789 |
| | 950 mb | 0.810 | 2.882 | 1.702 | 3.146 |

**Note*:** IORD-II requirements for temperature in cloudy:

-Uncertainty (surface to 700 mb: 2.5K per 1km layer, 700 mb to 300 mb: 1.5K per 1 km layer, 300 to 30 mb: 1.5K per 3km layer, 30 to 1mb: 1.5K per 5km layer)

*These requirements are for CrIS and ATMS, which have more channels and higher sensing skills in general than AMSU, MHS or SSMIS

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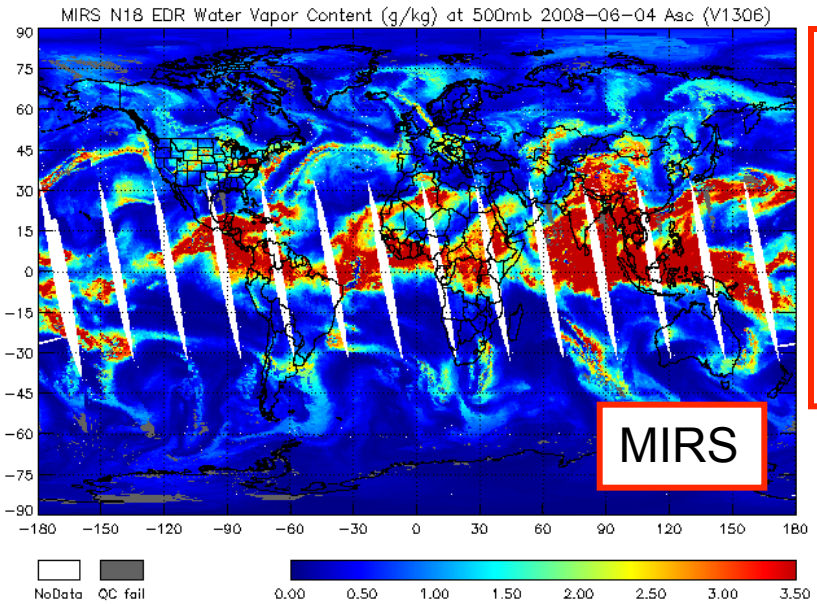
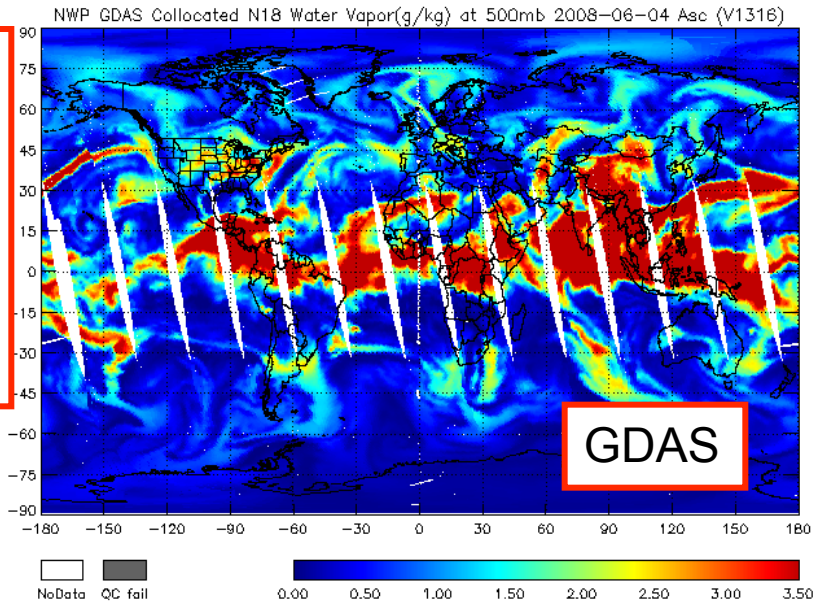
# Moisture Profile (1/4)

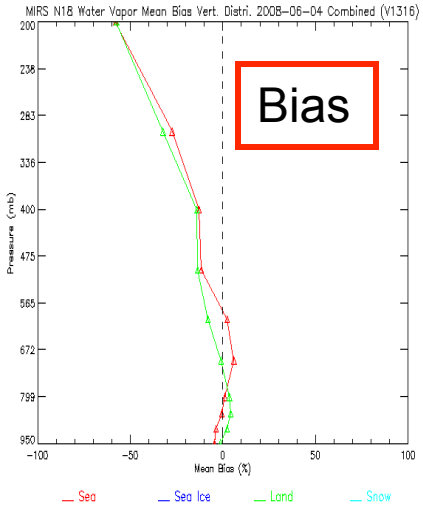
## (over open water and land, against GDAS)

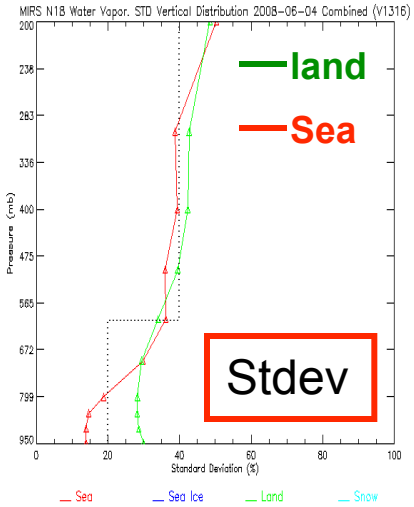



**Validation of WV done by comparing to:**
-GDAS
-ECMWF
-RAOB

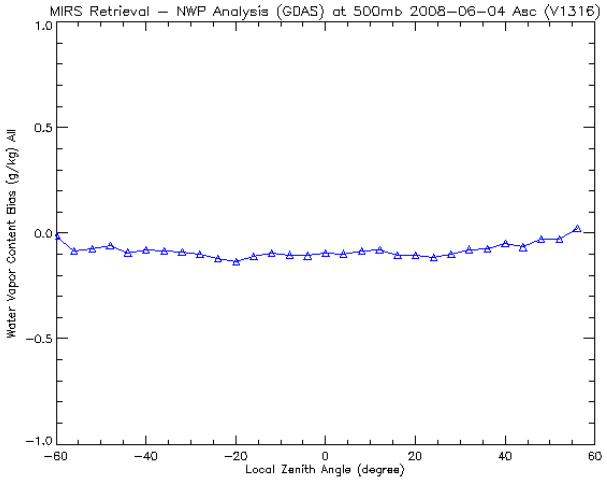
**Retrieval done over all surfaces in all weather conditions**



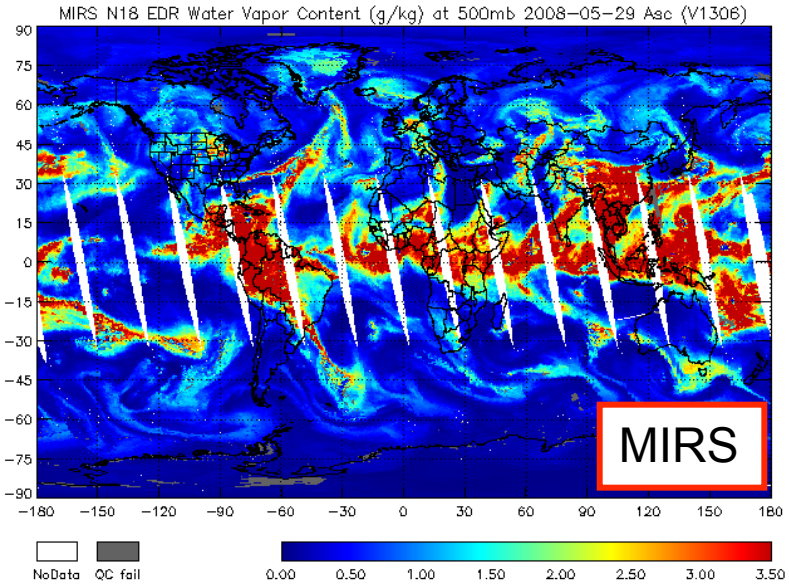

**Assessment includes:**
-Angle dependence
-Statistics profiles
-Difference maps




N18

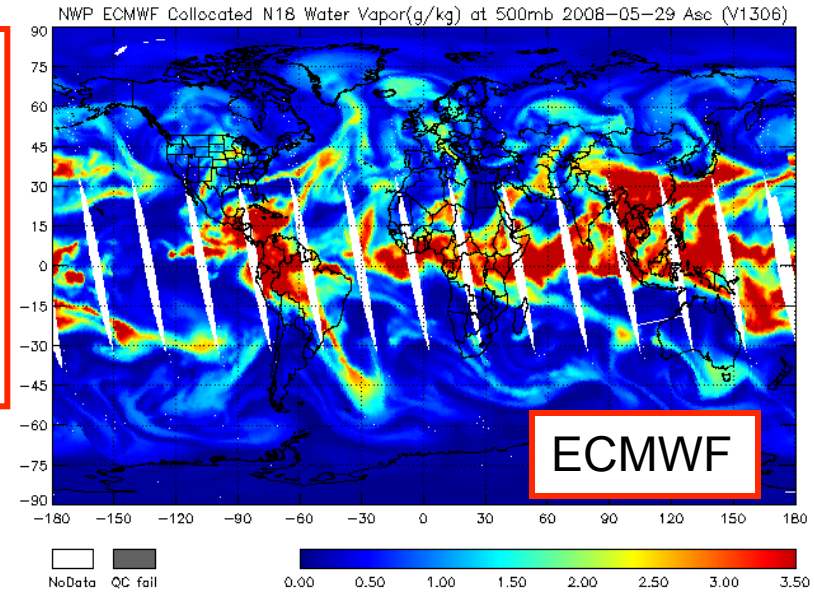
# Moisture Profile (2/4)

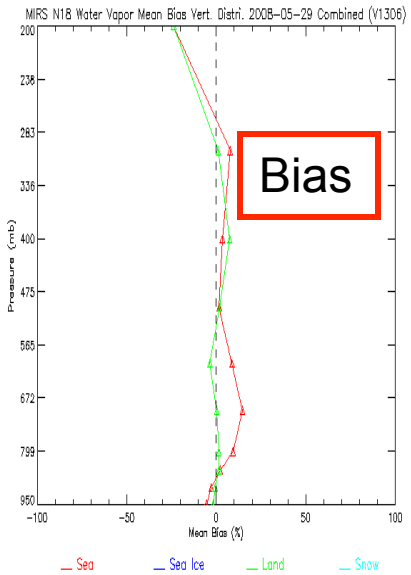
## (over open water and land, against ECMWF)

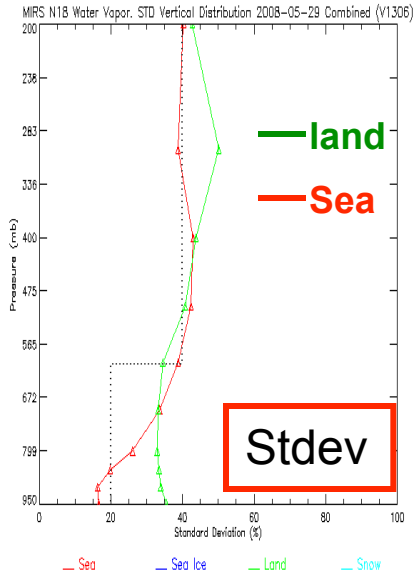



**Validation of WV done by comparing to:**
-GDAS
-ECMWF
-RAOB

**Retrieval done over all surfaces in all weather conditions**




**Assessment includes:**
-Angle dependence
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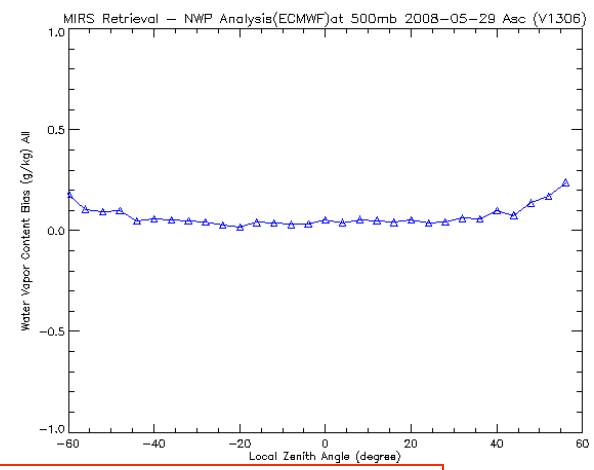


**When assessing, keep in mind all ground truths (wrt GDAS, ECMWF, RAOB)**

**N18**

# Moisture Profile (3/4)

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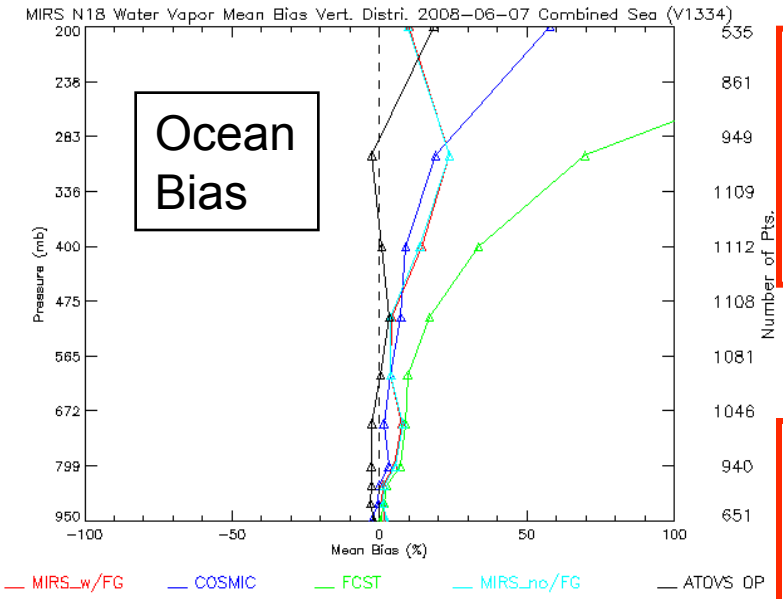
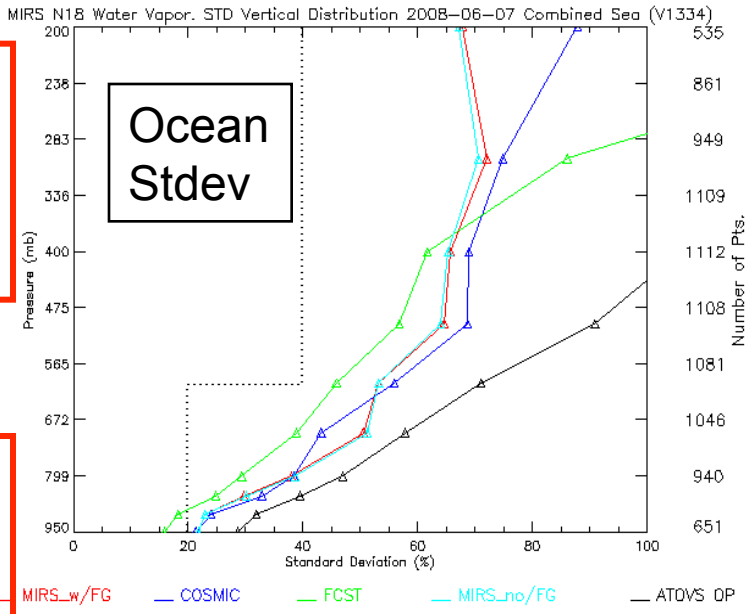
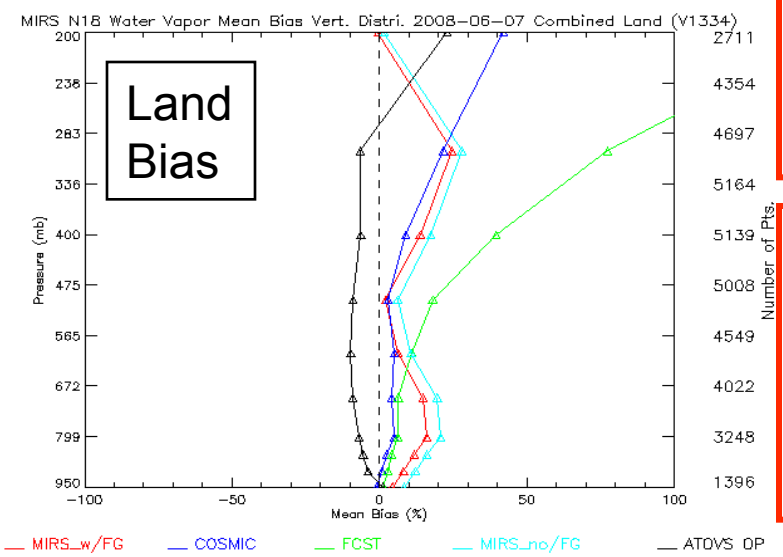
## (over open water and land, against RAOB, COSMIC, Forecast, ATOVS)



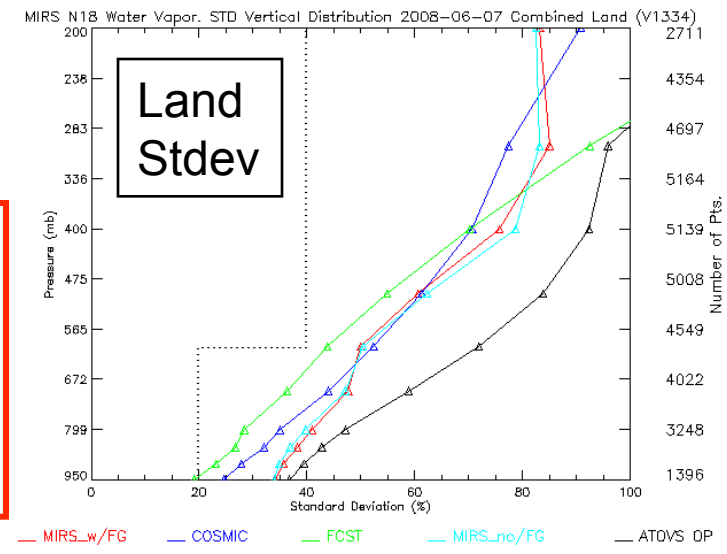

Stdev is found very good over land and ocean




MIRS is compared to Raob (along with COSMIC, ATOVS and Forecast)




Bias wrt RAOB (over land) not consistent with ECMWF and GDAS



# Moisture Profile (4/4)

## (Performances)

| | Layer | Ocean Bias (%) | Ocean Std (%) | Land Bias (%) | Land Std (%) |
|---|---|---|---|---|---|
| *MIRS vs ECMWF* | 100 mb | | | | |
| | 300 mb | 8.0 | 41.0 | 1.5 | 54.0 |
| | 500 mb | -0.5 | 42.5 | -1.5 | 41.0 |
| | 800 mb | 11.0 | 28.0 | -1.0 | 32.5 |
| | 950 mb | -5.0 | 17.0 | -5.5 | 32.0 |
| *MIRS vs GDAS* | 100 mb | | | | |
| | 300 mb | -29 | 40.5 | -30.0 | 53.0 |
| | 500 mb | -10.0 | 39.5 | -15.0 | 38.5 |
| | 800 mb | 2.0 | 22.0 | 8.0 | 30.0 |
| | 950 mb | -5.5 | 13.5 | 3.0 | 30.0 |
| *MIRS vs RAOB* | 100 mb | | | | |
| | 300 mb | 21.5 | 75.0 | 21.0 | 83.0 |
| | 500 mb | 2.0 | 65.0 | 1.0 | 60.0 |
| | 800 mb | 2.0 | 38.0 | 7.0 | 41.0 |
| | 950 mb | 0.5 | 21.5 | 4.0 | 30.0 |

**Note*: IORD-II requirements for Water Vapor Mixing Ratio (in g/Kg), for cloudy:**

**-Uncertainty (surface to 600 mb: greater of 20% or 0.2 g/Kg, 600 mb to 100 mb: greater of 40% or 0.1 g/Kg) [expressed as percent error of average mixing ratio in 2km layers]**

**- No measurement precision**

*These requirements are for CrIS and ATMS, which have more channels and higher sensing skills in general than AMSU, MHS or SSMIS

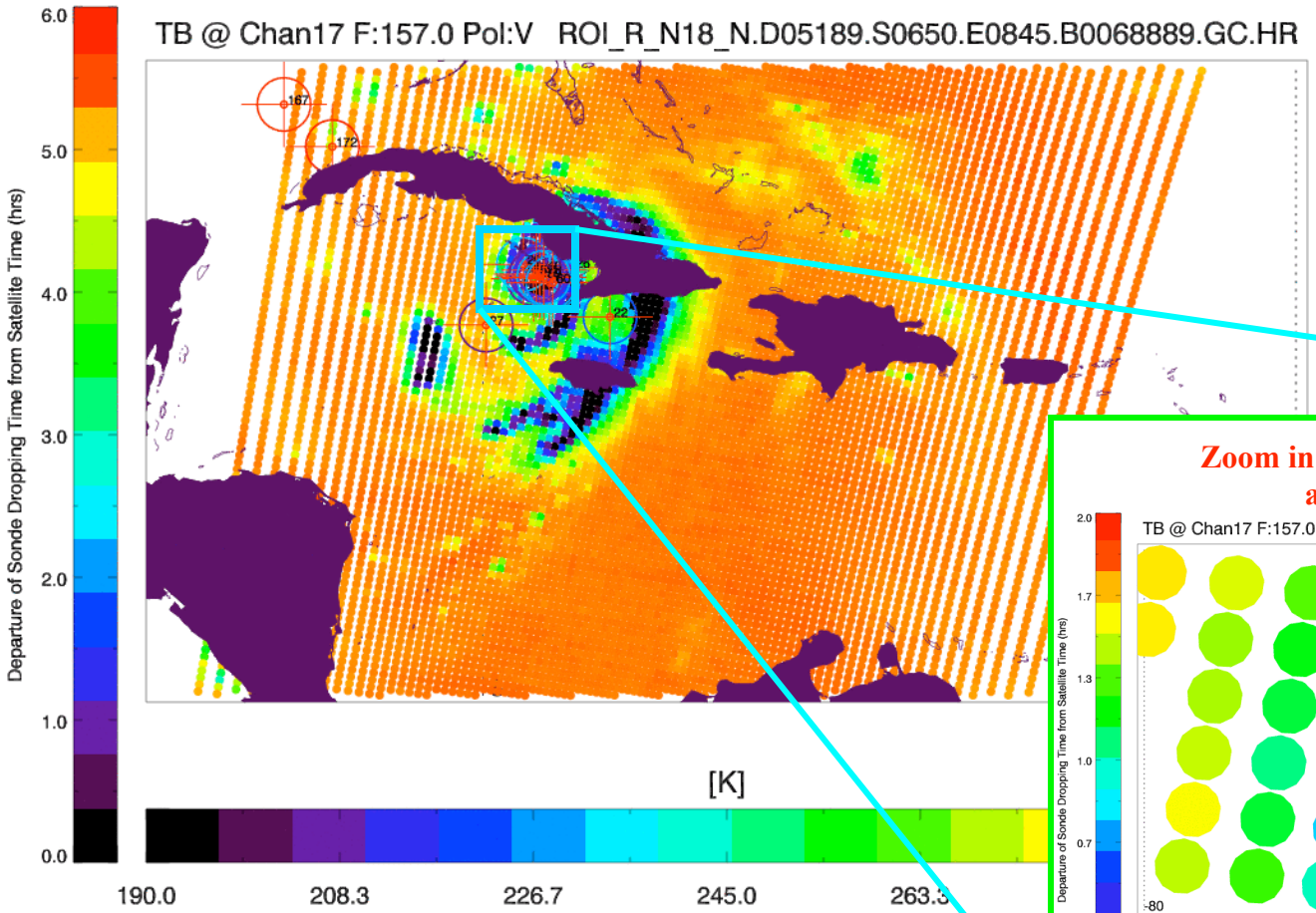
# Assessment of Sounding Performances in Hurricane conditions

*A tricky issue to say the least because of:*
*- Highly variable meteorological conditions (in time and space)*
*- Collocation errors*
*- Moving target (sondes sample different parts of the atmosphere while dropping/ascending)*
*- Representativeness errors (spot vs footprint)*
*- Intra variability of ground truth measurements*
*- 3D effects on TBs*

# Assessment of Sounding in Hurricane Conditions

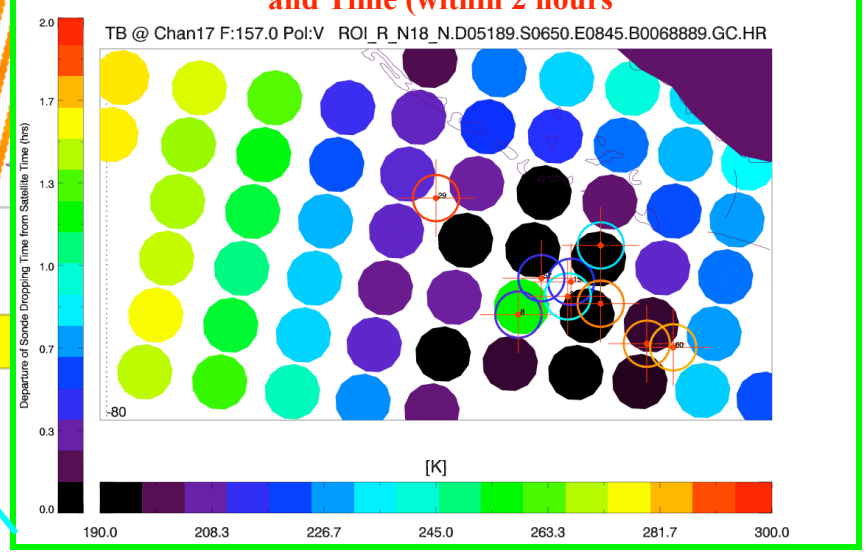
Collocation with GPS-Dropsondes

- **Case of July 8th 2005 (descending pass)**




**MHS footprint size at nadir is 15 Kms. But at this angles range (around 28º), the MHS footprint is around 30 Kms**

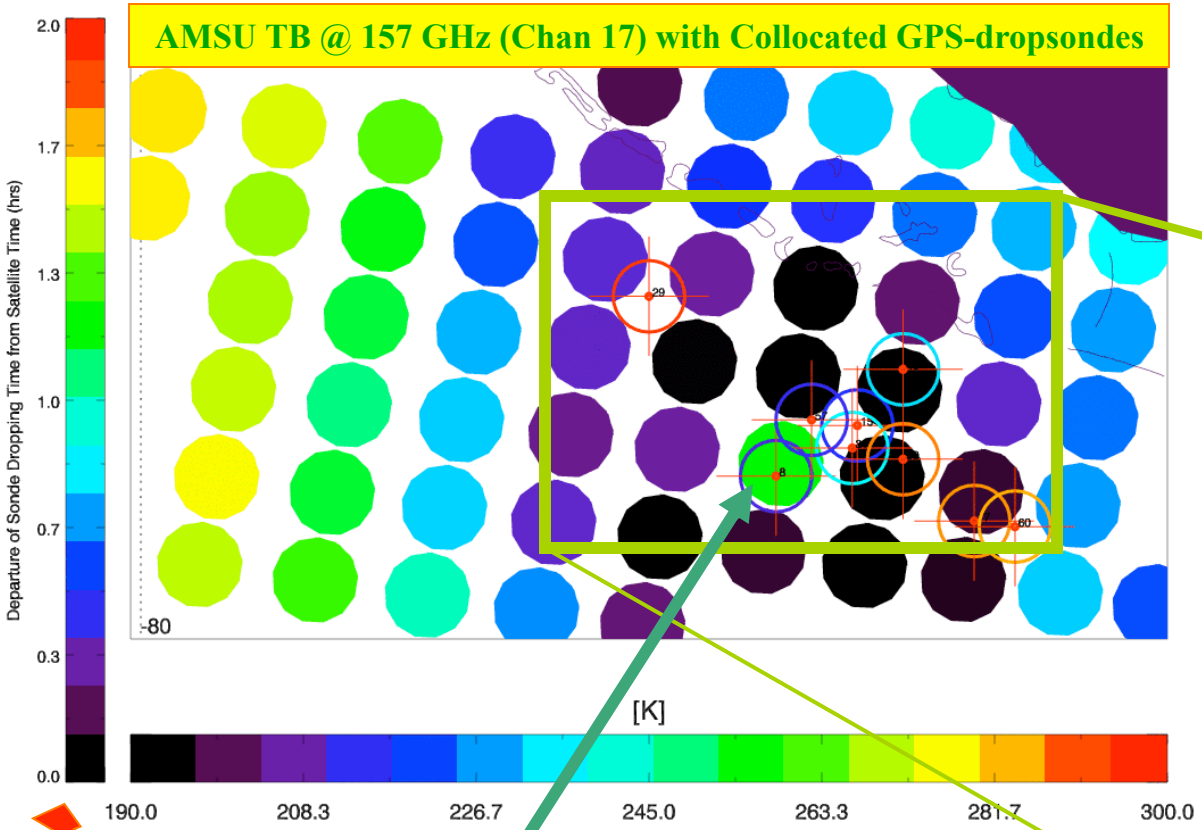
**Zoom in space (over the Hurricane Eye) and Time (within 2 hours**



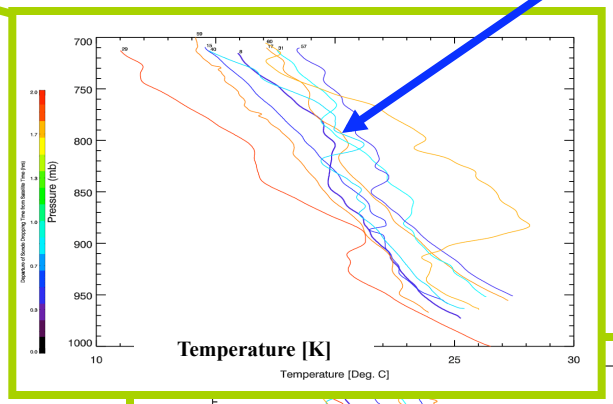
# Collocation AMSU/MHS with GPS-Dropsondes (2nd case)

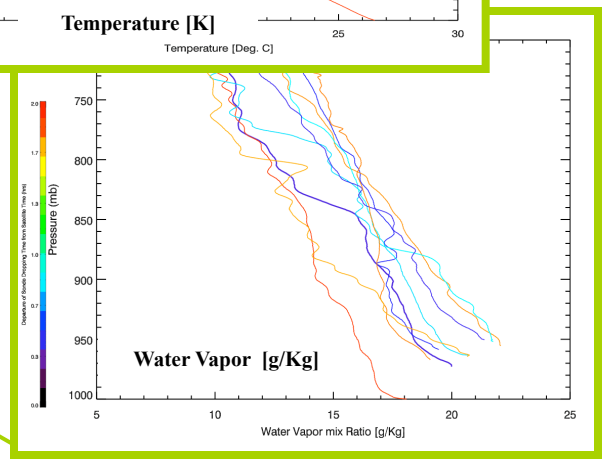
**A peak at the vertical profiles measured by the dropsondes**

- **Case of July 8th 2005 (descending pass)**




Sonde in Hurricane Eye



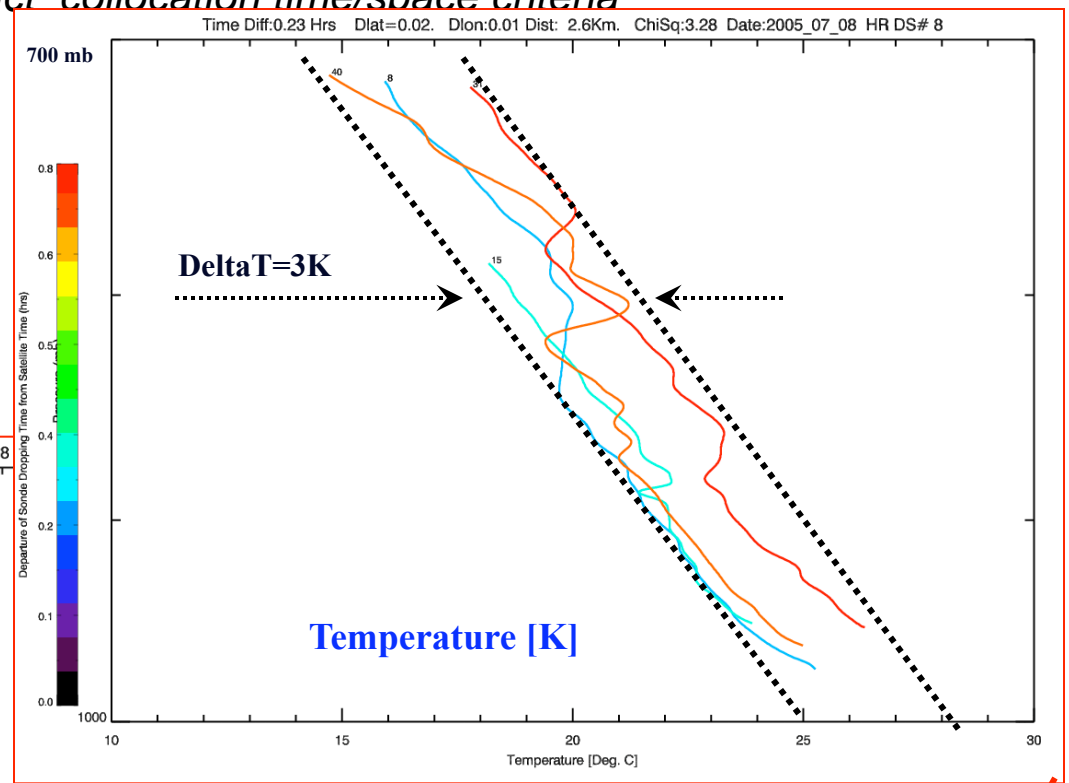



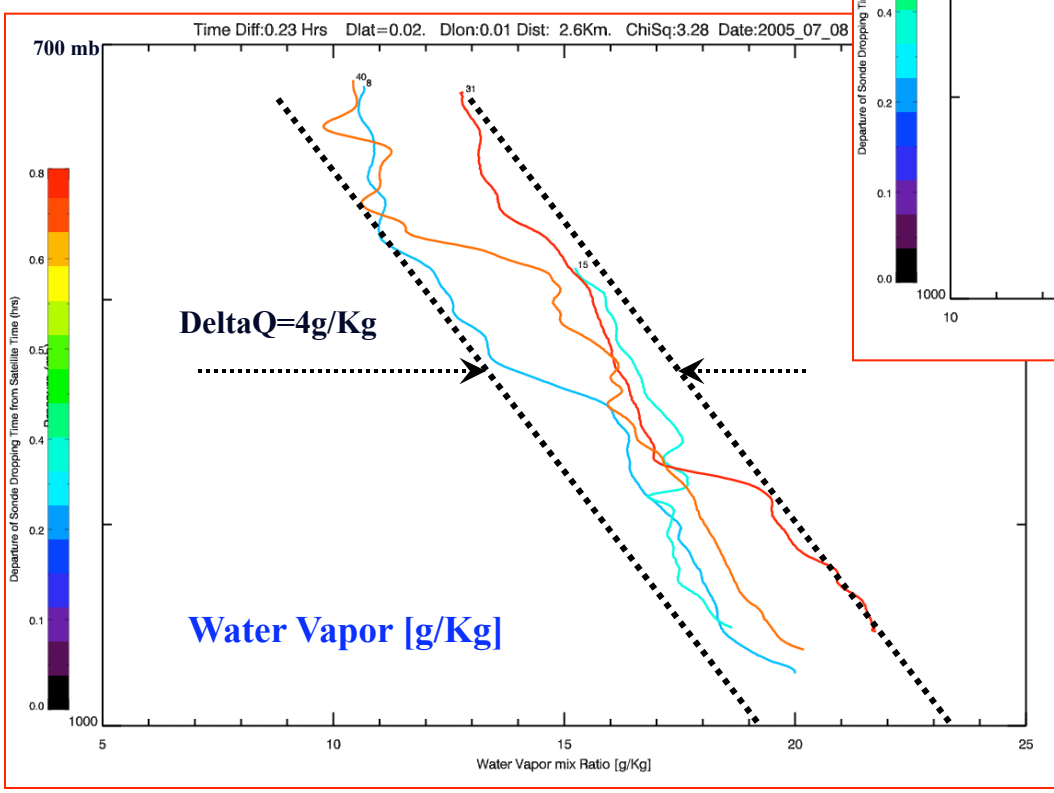

**Collocated GPS-dropsonde (in space and within few minutes in time) with NOAA-18 in the Hurricane Eye**

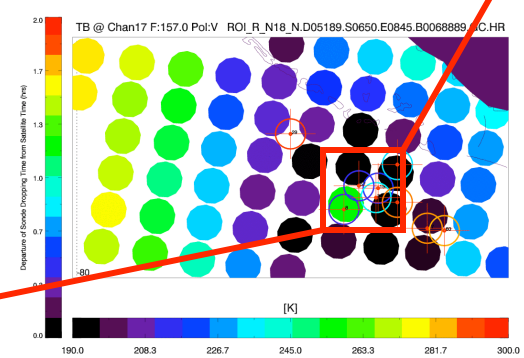
# Natural/Dropsondes Intra-variability

*Within the very strict collocation time/space criteria*

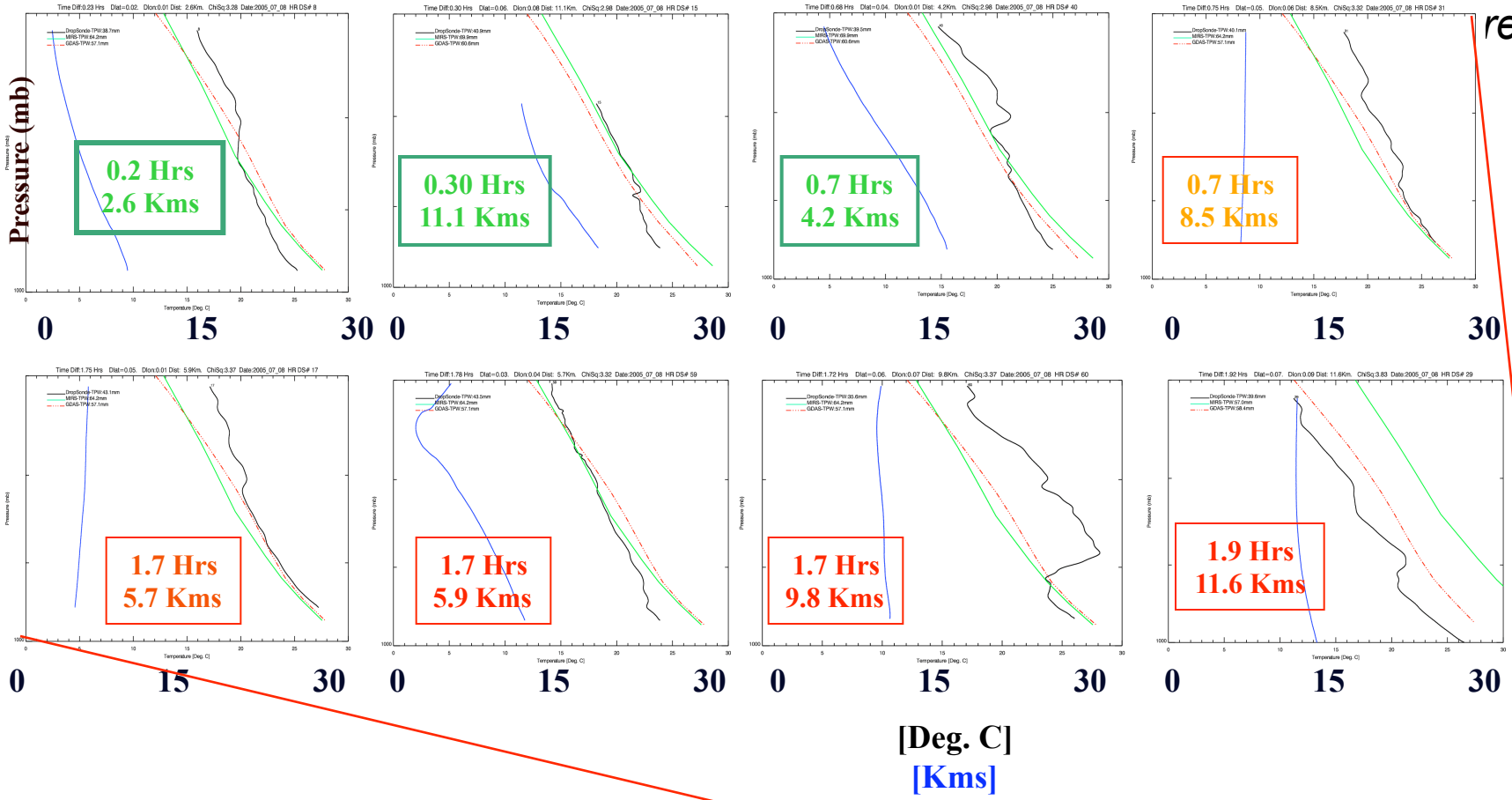
**All these 4 Dropsondes were dropped within 45 minutes and are located within 10 kms from each other**



# Case-By-Case Comparison with Dropsondes Measurements (Case#2)




region)

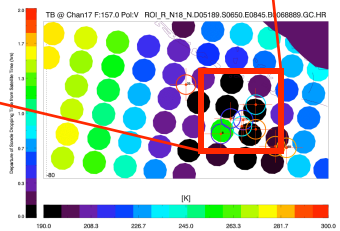
The more distant (in time and space) the DS are from the measurements, the worse the performances are.

Retrieval

GDAS

DropSonde

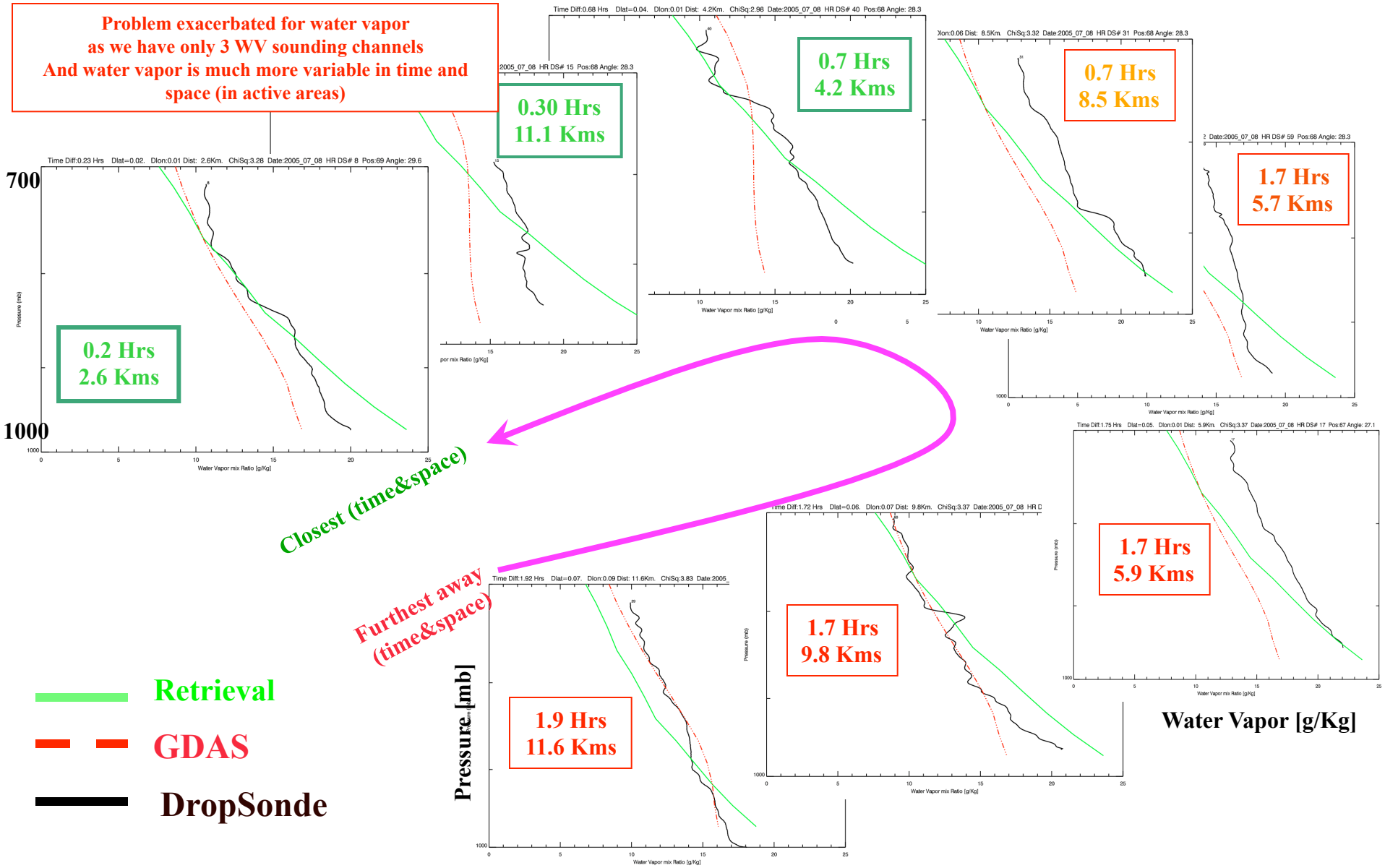
Profile of DS Distance Departure



# Case-By-Case Comparison with Dropsondes Measurements (Case#2)

*-Dennis Hurricane- WATER VAPOR PROFILE (Zoom over 700-1000 mb region)*

**Problem exacerbated for water vapor as we have only 3 WV sounding channels And water vapor is much more variable in time and space (in active areas)**

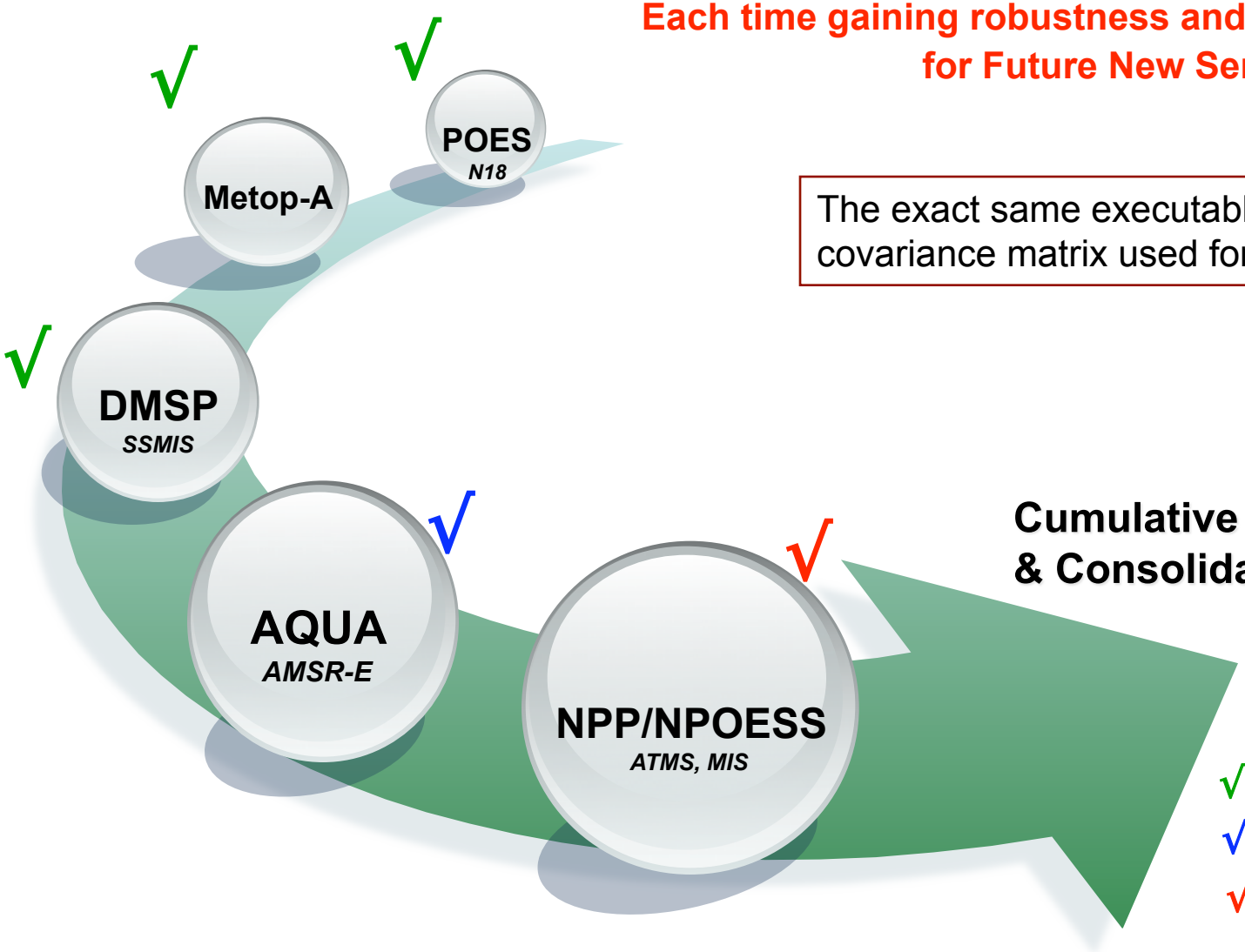


# Plans for ATMS

# Getting ready for NPP and NPOESS

**MIRS is applied to a number of microwave sensors,**
**Each time gaining robustness and improving validation**
**for Future New Sensors**

The exact same executable, forward operator, covariance matrix used for all sensors




**Cumulative Validation & Consolidation of MIRS**

√: Applied Daily

√: Applied occasionally

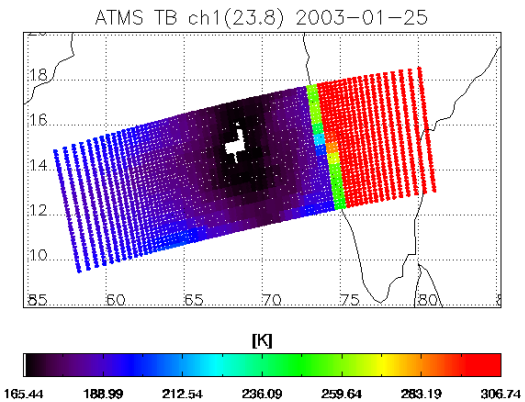
√: Tested in Simulation

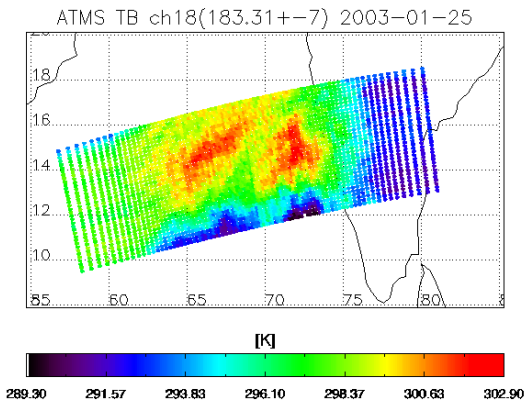
# Running MiRS for ATMS

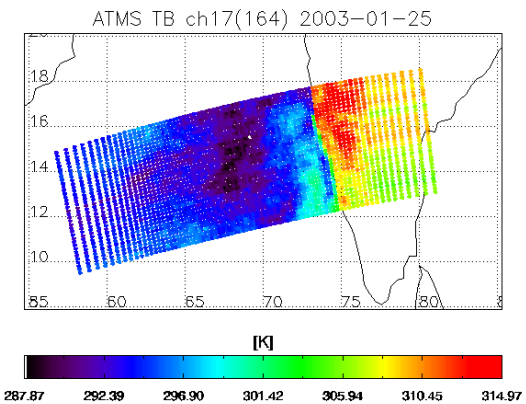
- Same code used for ATMS (leverage a lot of effort performed for N18, Metop-A, DMSP,AMSR-E, etc)
- External files needed:
  - Noise file (both instrument and RTM uncertainty)
  - Emissivity Covariance Matrix
  - CRTM Look-Up-Tables
- Data access: through NDE NPOESS Data Exploitation (NDE): MiRS will run on NDE
- Work accomplished:
  - Reader of HDF-5 files ready to process data

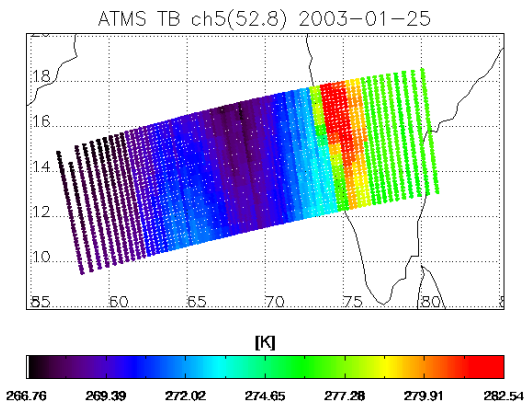
# ATMS Radiances

- ATMS SDR sample files provided through NDE (by NGST) in HDF-5 format.
- Decoder/encoder ready.
- Plan: simulate ATMS radiances on a daily basis to generate proxy ATMS data to test MiRS on



# Conclusions & Talking Points

# Discussion (1/2)

- MiRS sounding Performances were assessed using different sources. Sometimes results are different, reflecting inter-truth variability.
- When consistent behavior is noticed, assumed that MIRS is the likely reason
- SSMIS is found, as expected from radiances noisiness, to have slightly more degraded performances (than N18) –*Not shown here-*
- N18 and Metop-A running at AMSUA resolution
- SSMIS running at UAS resolution
- TPW is extended to all surfaces [Ocean, Land, Sea ice and Snow] operationally for NOAA-18 and Metop-A, for the first time.
- Retrieval is performed (and convergence reached) in cloudy, rainy, ice-impacted scenes

# Discussion (2/2)

- MiRS is ready to be applied to ATMS (NPP): No issues expected
- Leverage of previous work for N18, MetopA and DMSP SSMIS will have direct positive impact on ATMS readiness (and likely validity)
- MiRS will assimilate (retrieve) all ATMS data (over all surfaces and in all-weather conditions)
- Assessment in clear/cloudy conditions pretty good.
- Assessment in all-weather conditions much tougher.
- <u>Suggested further work:</u>
  - Use ATMS retrievals as first guess to CrIS/ATMS?
  - Given that CRTM is valid in IR/MW and MiRS technology is not spectrum-dependent, Use MiRS for IR/MW synergy?

# BACKUP SLIDES

# Nominal approach: Simultaneous Retrieval

*Necessary Condition (but not sufficient)*

**F(X) <u>Does not</u> Fit $Y^m$ within Noise**

**X is <u>not</u> the solution**

**F(X) <u>Fits</u> $Y^m$ within Noise levels**

**X is <u>a</u> solution**

**X is <u>the</u> solution**

All parameters are retrieved simultaneously to fit all radiances together

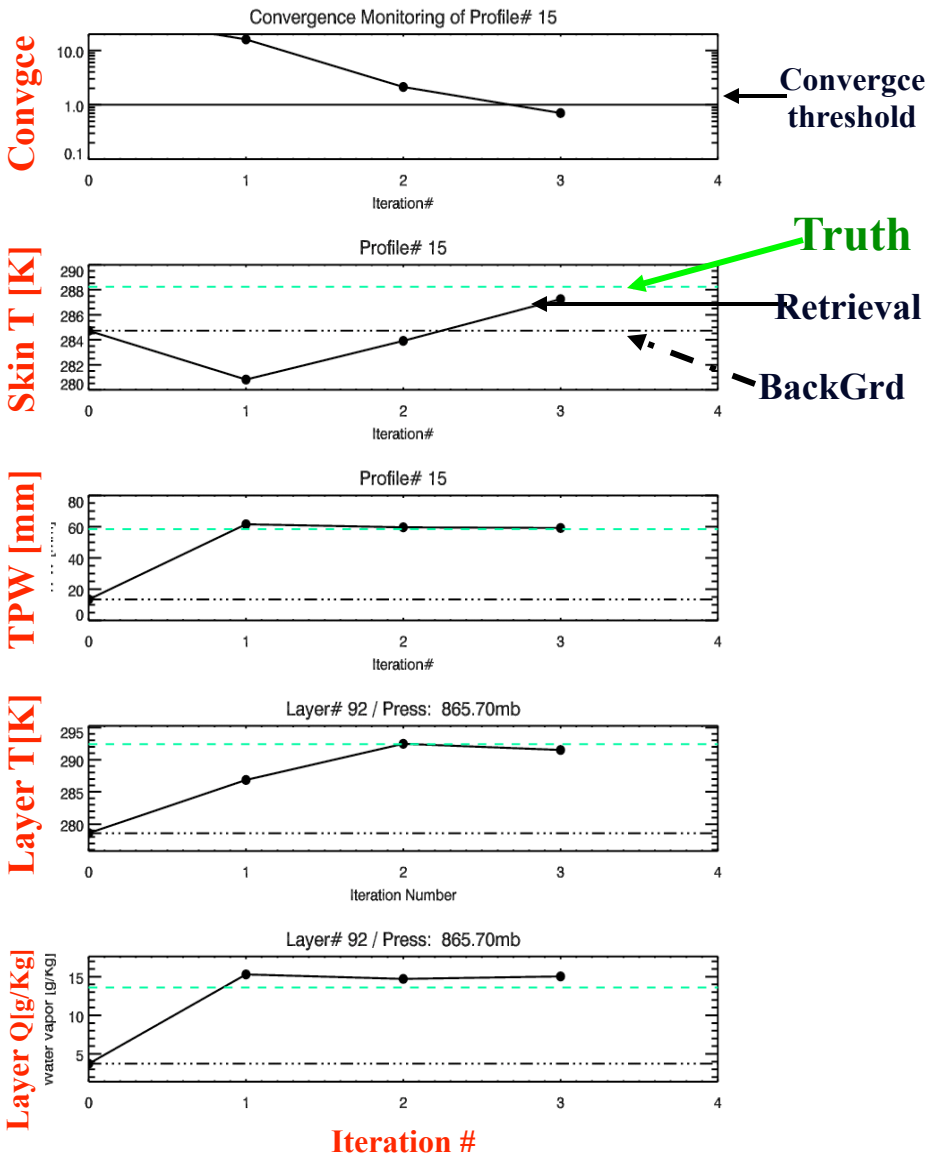
# Handling Channel Degradation / Failure

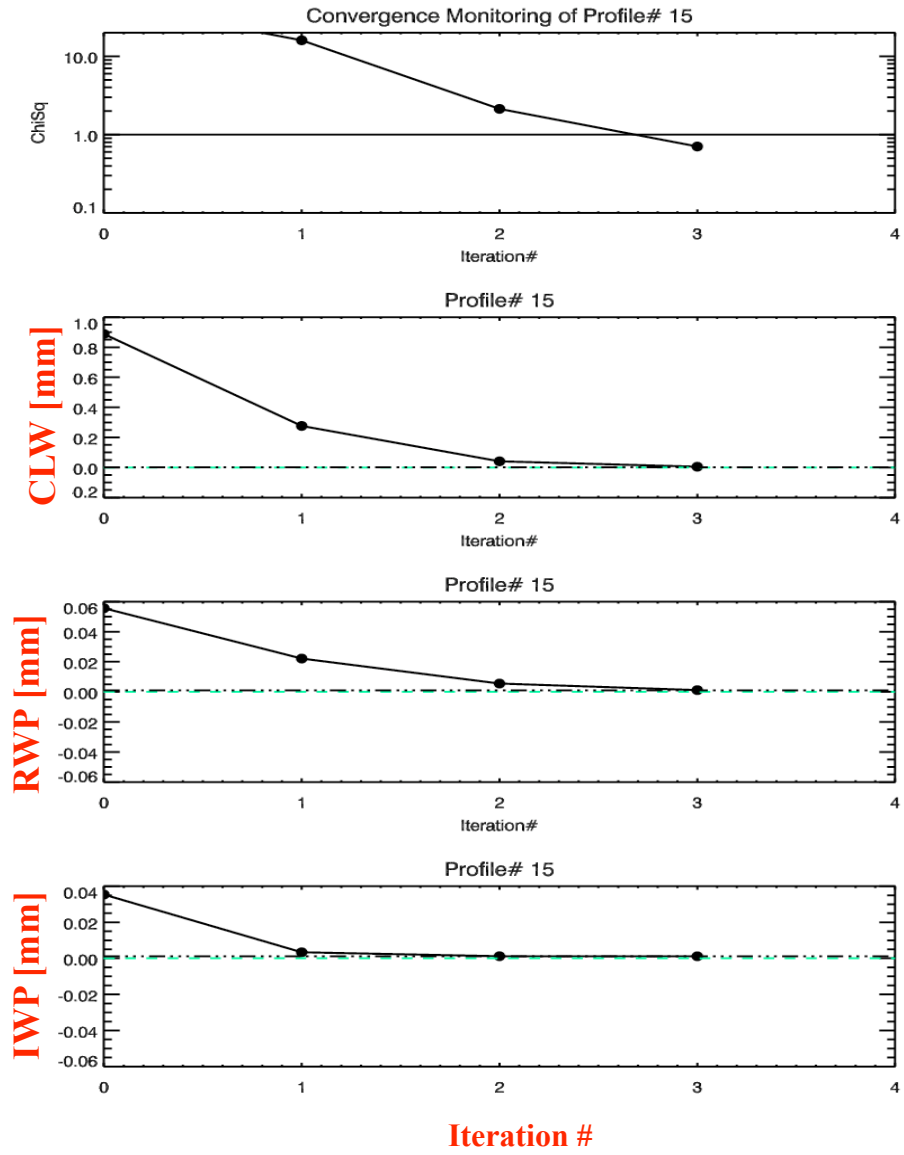
- Instrument NEDT (AMSU/MHS) is computed dynamically from Level1B data, then fed to retrieval, along with RTM uncertainty
- If a channel' NEDT is high, channel will have less weight in retrieval
- Similarly, if RTM precision for a channel is low, it will have less weight in retrieval
- If channel is declared *failed*, MIRS has ability to turn it OFF by a switch

**MIRS 1DVAR Algorithm is still valid (by concept) even if:**
**-Noise becomes higher,**
**- If channel fails**

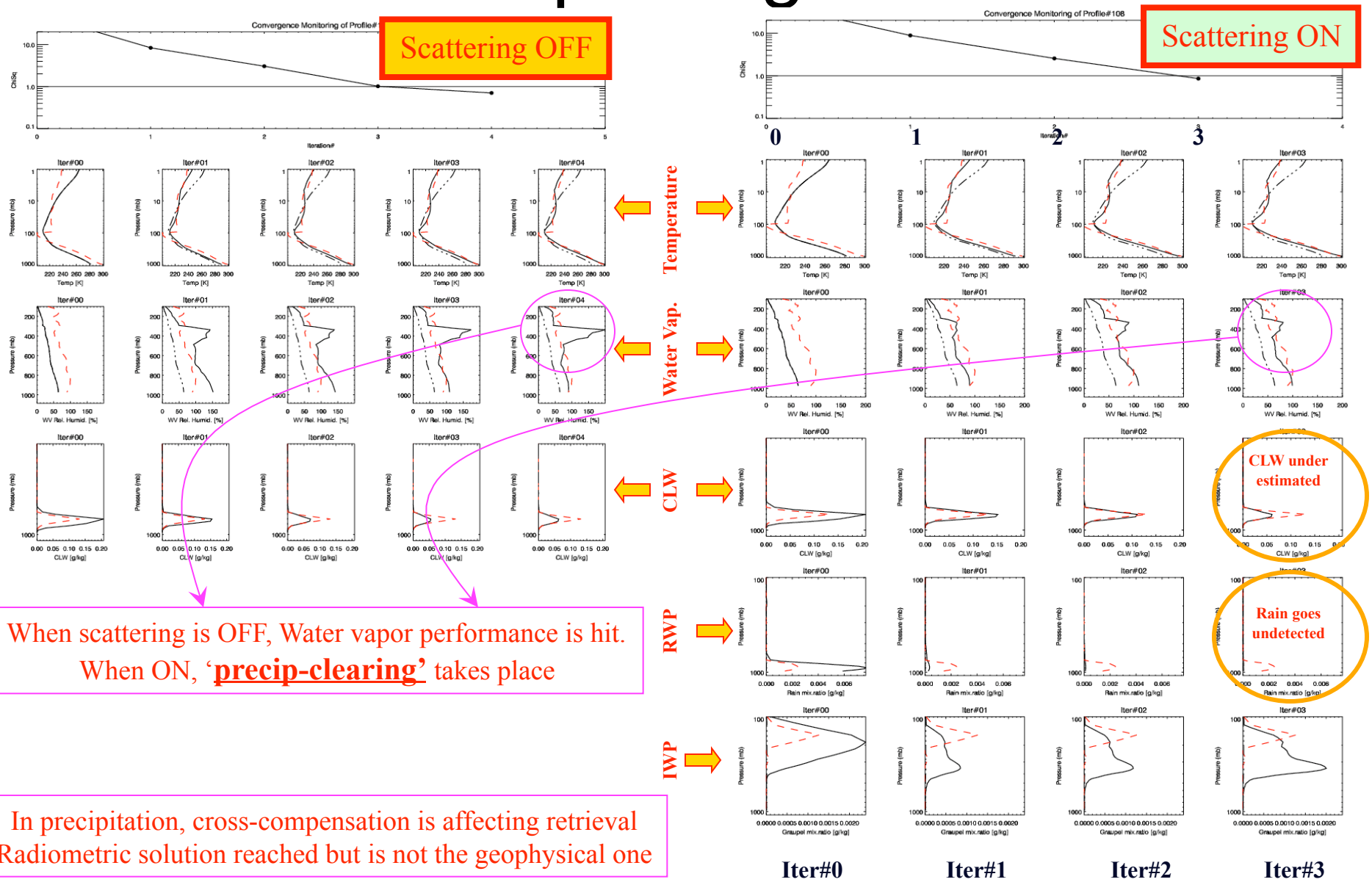
Note: This does not prevent performances from degrading

# Illustration of the System Functionality



# Assessment in a Precipitating Case

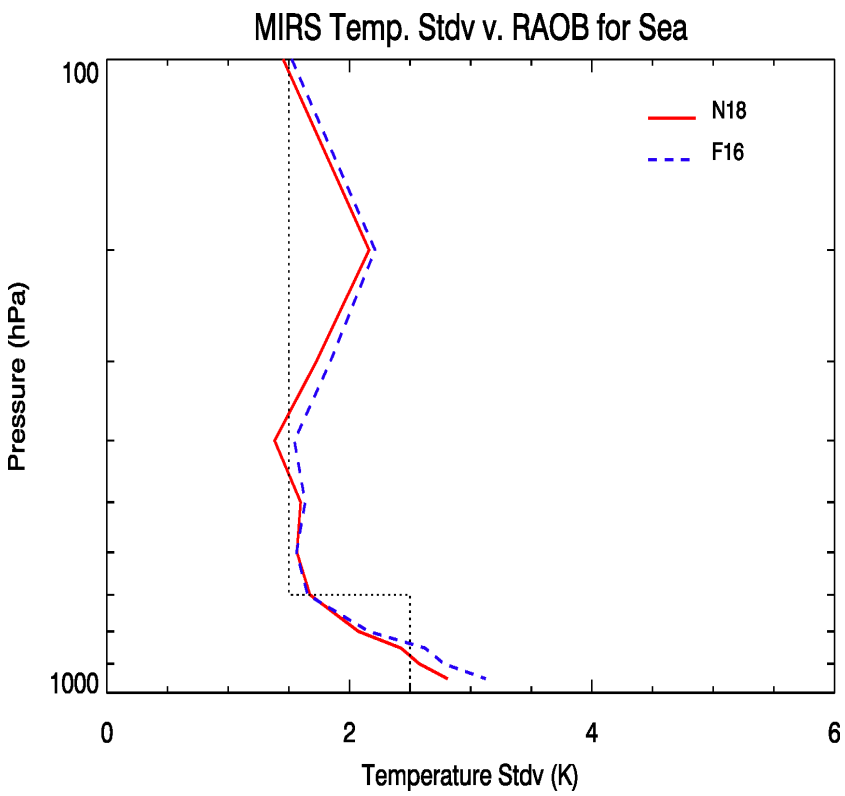


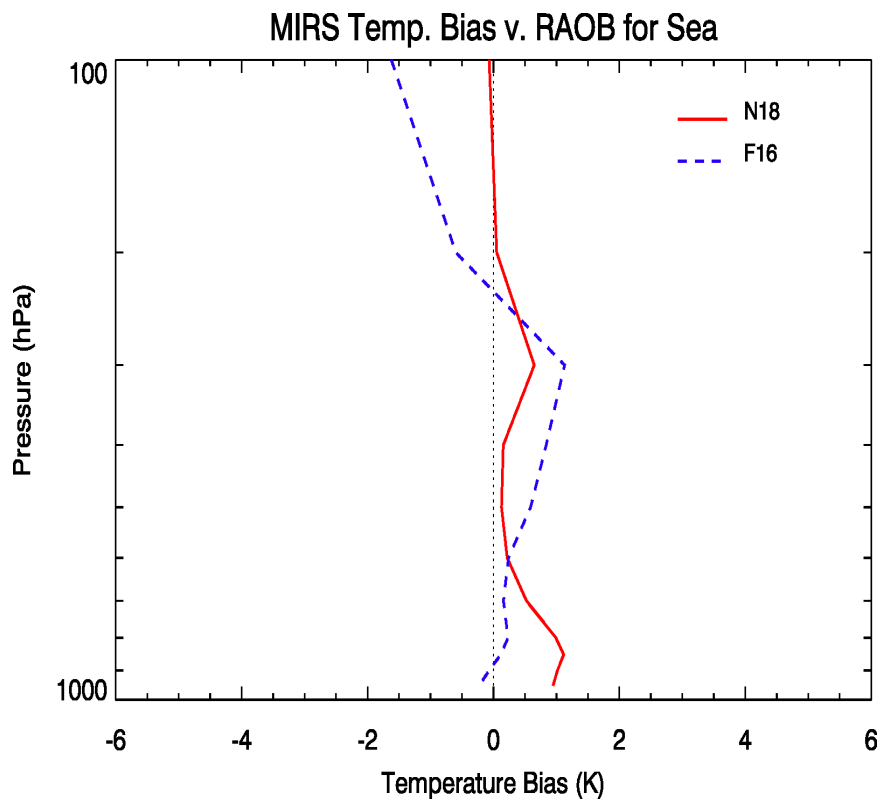

When scattering is OFF, Water vapor performance is hit.
When ON, '**precip-clearing'** takes place

In precipitation, cross-compensation is affecting retrieval
Radiometric solution reached but is not the geophysical one

# Comparison of Performances (N18 vs SSMIS)

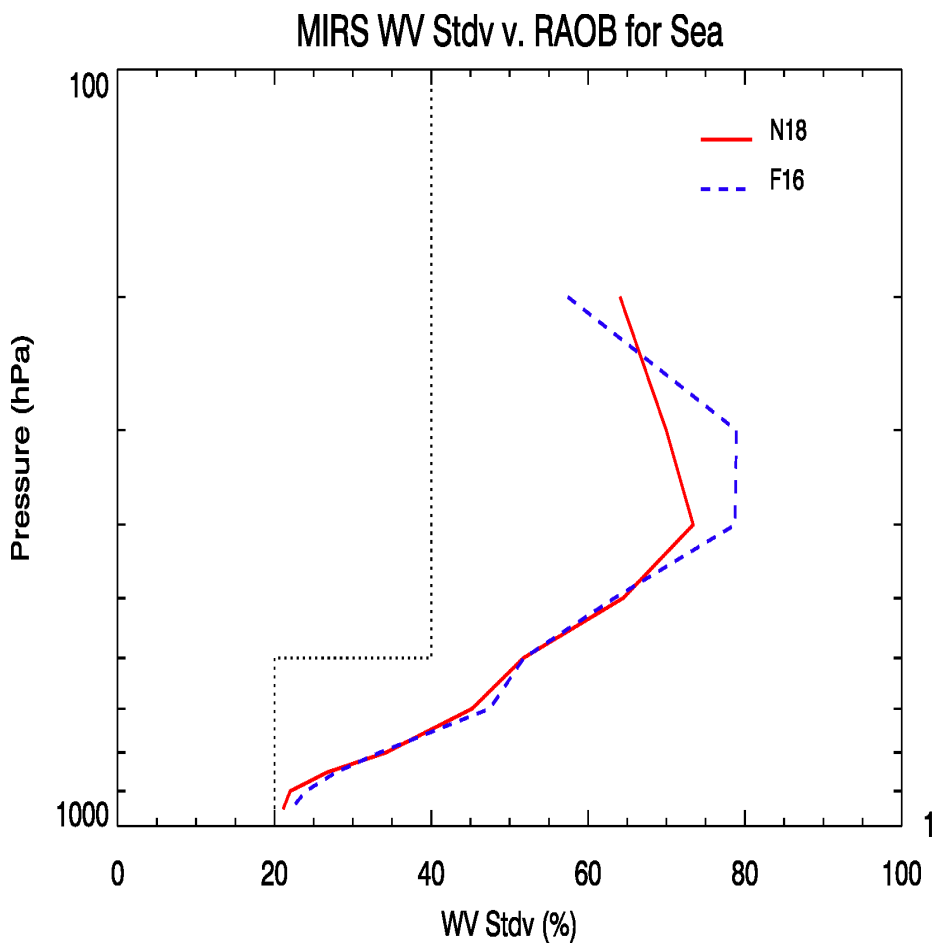
# Temperature Performances (Sea)

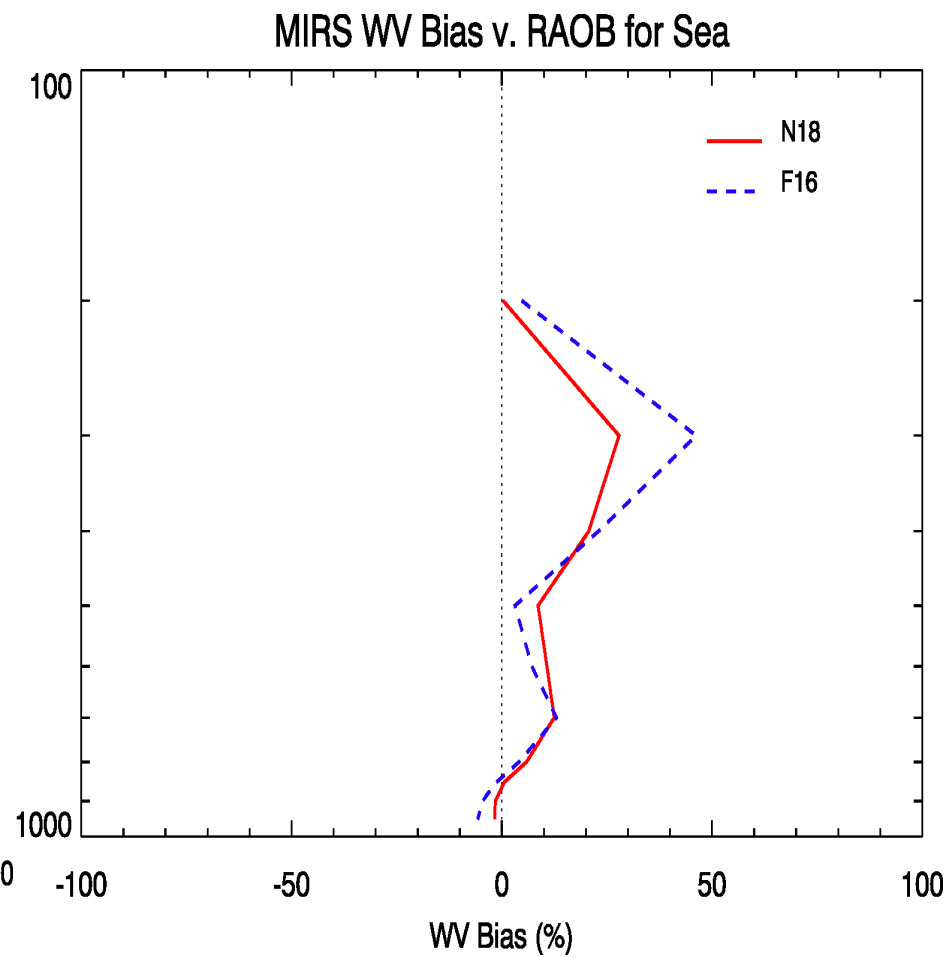



**RAOBs used as a reference. Several months worth of data used.**

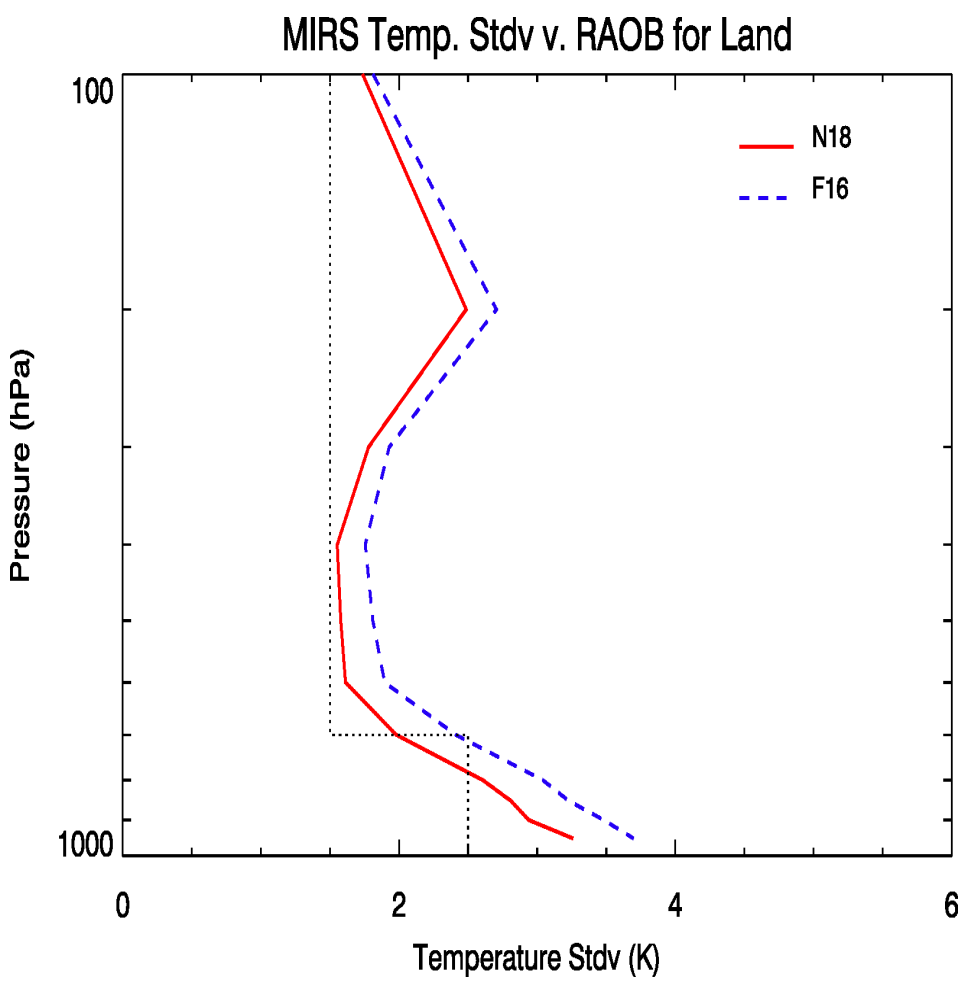
# Moisture Performances (Sea)

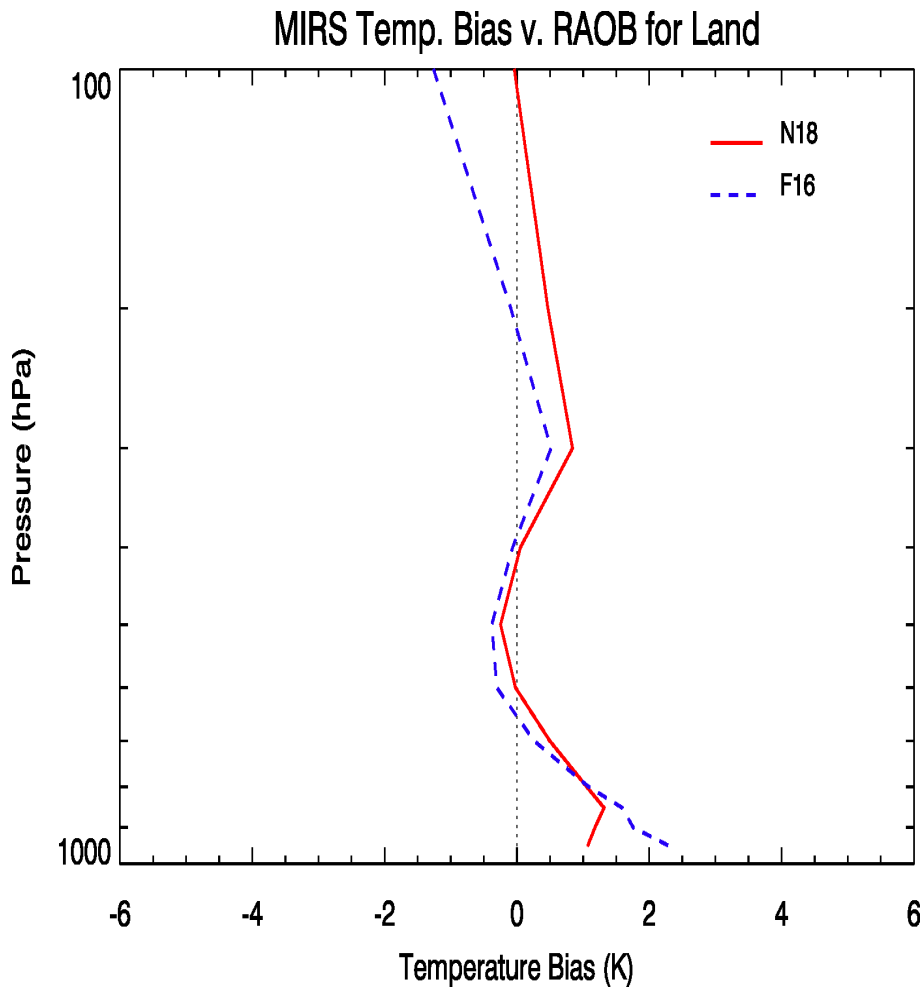



**RAOBs used as a reference. Several months worth of data used.**

# Temperature Performances (Land)

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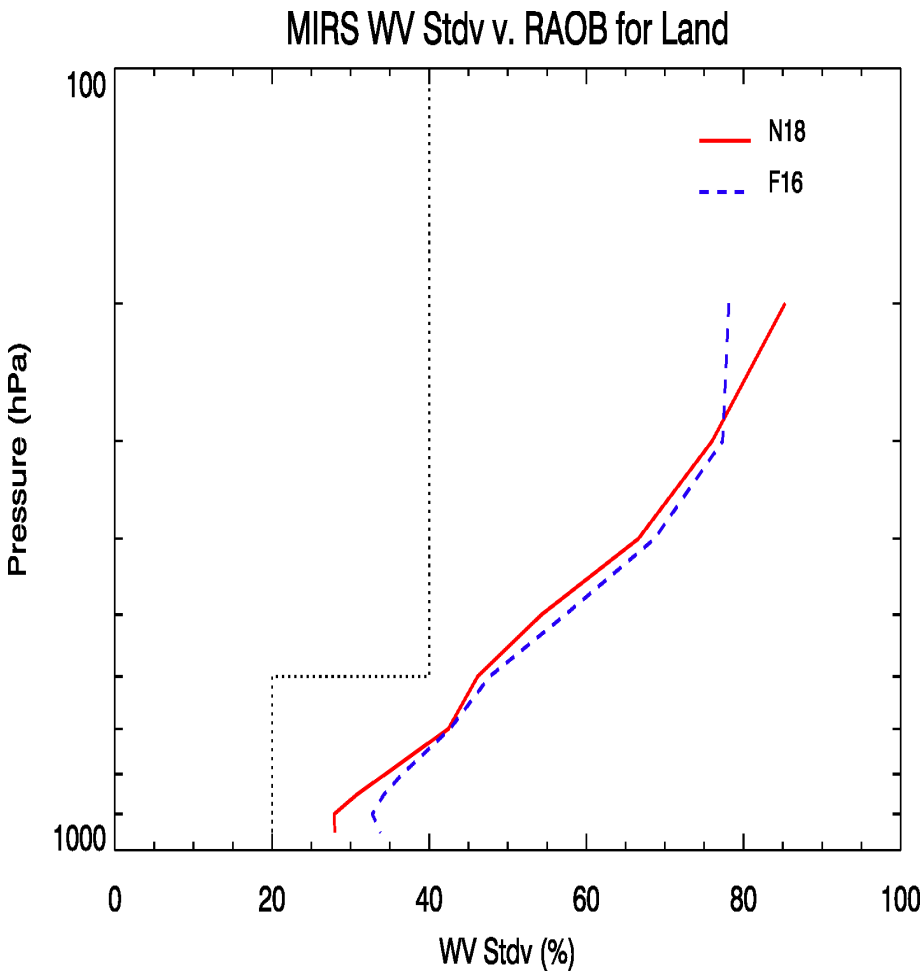
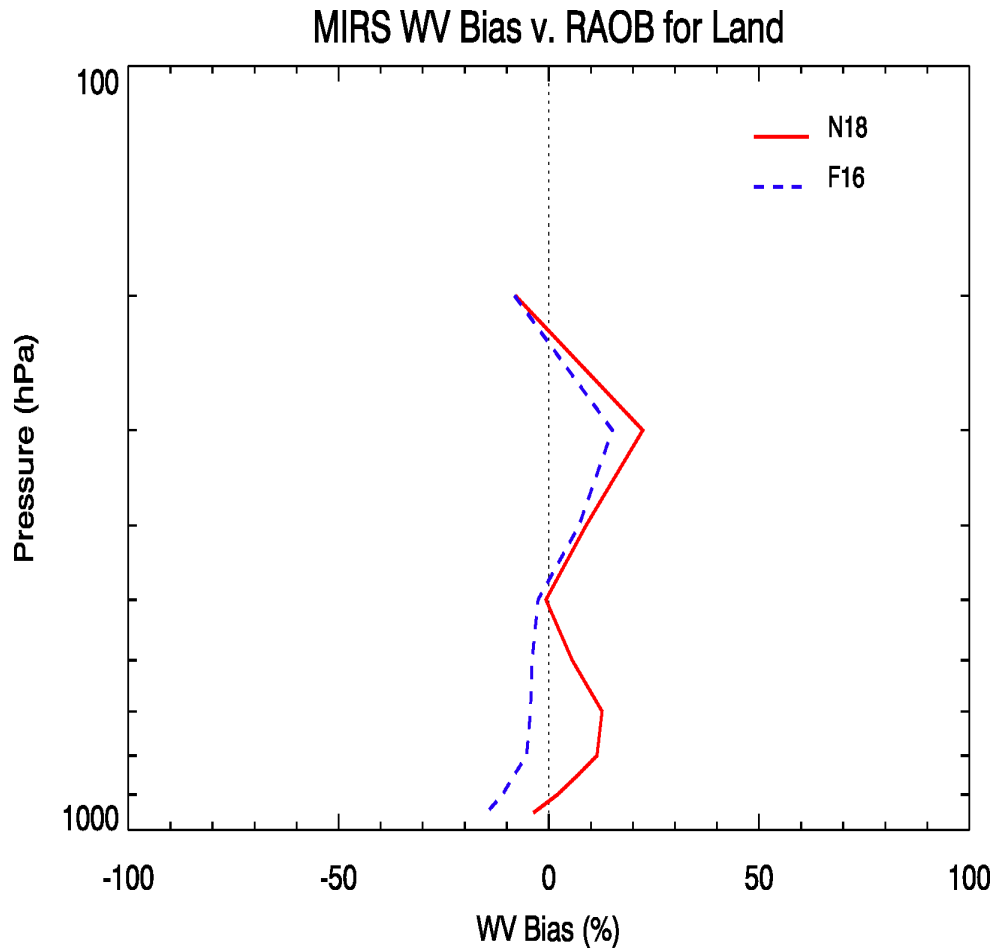
# Moisture Performances (Land)

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